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Exploration Crew Transportation System Requirements Document (Spiral 2)

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Crew Transportation System Requirements Document (Spiral 2)

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1 Scope

1.1 Identification

This document is a summary of the NASA Crew Transportation System (CTS) requirements, as configured to execute missions during Exploration Spiral 2. *Internal note: Currently, this document contains only Crew Exploration Vehicle (CEV) and Crew Exploration Vehicle Launch Segment (CEVLS) requirements. Earth Departure Stage (EDS) and Lunar Surface Access Module (LSAM) requirements will be added at a future date.* These requirements represent a functional decomposition of the requirements expressed in the Exploration System of Systems Technical Requirements document, ESMD-RQ-0010, **(TBD-1)**. Ultimately, the requirements in this document can be traced back to the requirements expressed in *The Vision for Space Exploration* (hereafter referred to as The Vision), February 2004, and captured in the Level 0 Exploration Requirements for the National Aeronautics and Space Administration, SA-0001, May 4, 2004.

The capabilities expressed in this document will evolve and expand over time, employing the Spiral Development Process to develop human-crewed, cargo, and robotic flight and ground systems to accomplish The Vision. Emphasis has been on the Crew Exploration Development and Test requirements (Exploration Spiral 1) and the Lunar Exploration requirements (Exploration Spirals 2&3), that provide long-duration human lunar exploration capability. Requirements development for Exploration Spiral 4 and beyond (human-Mars exploration) will be undertaken in the future. The controlling authority for this document is the Exploration Systems Mission Directorate (ESMD), Requirements Formulation Division, NASA Headquarters.

1.2 Document Overview

This document provides the CTS requirements that will be functionally decomposed and captured in supporting elements of the CTS. The Exploration Systems Document Tree shown in Figure 1 explains the hierarchy of requirements documents that flow down from The Vision. The relationship of this document to other Exploration Systems requirements documents is shown in Figure 2.

Note: Where a requirement is expressed with "threshold and objective" values, it has been determined that performance above the threshold (minimum performance level) is of value to NASA as a desired "objective". Where no objective value is expressed, the value shown is the threshold requirement.

Section 1 of this document contains background information with no direct requirements. Section 2 contains the applicable documents that the CTS must comply with, as specified; Section 2 also includes reference documents that are for information only, and do not contain compliance requirements. Section 3 contains requirements that begin in Section 3.1. Section 4 contains definitions of requirements verification methods. Actual verification requirements do not appear in this document, and will be treated in lower level requirements documents. Section 5 provides a glossary of Exploration terms, an acronym list, and a requirements taxonomy table.

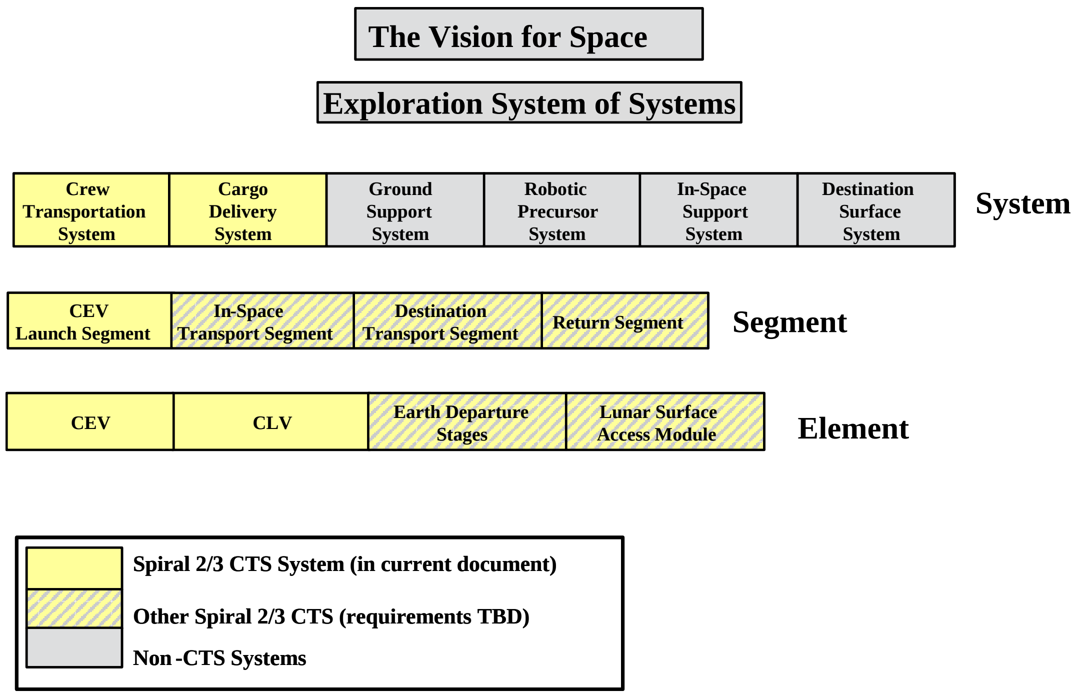

Figure 1: CTS Spiral 2 /3 System Hierarchy (flow-down shown for CTS only)

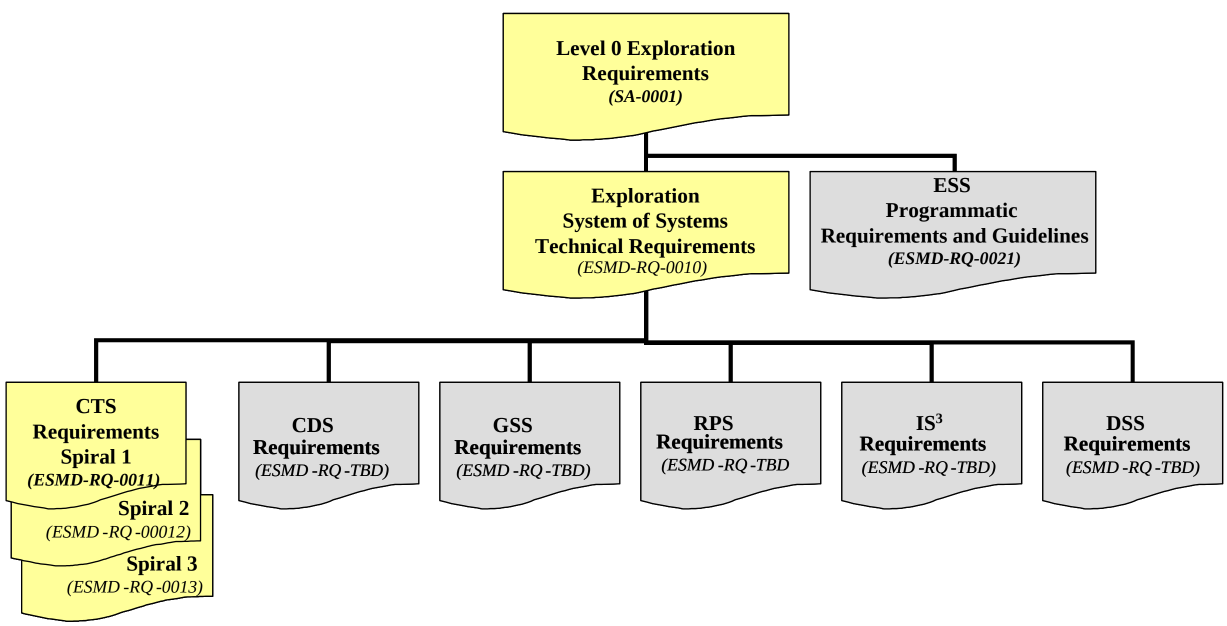

Figure 2: Exploration System Requirements Tree

2 Documents

2.1 Applicable Documents

The following documents form a part of this requirements document to the extent specified herein. The version of the document applicable will be the latest revision at the time of contract award unless otherwise specified.

2.1.1 Government Documents

The Vision for Space Exploration (NP-2004-01-334-HQ)

Level 0 Exploration Requirements for the National Aeronautics and Space Administration (SA-0001)

NPR 7150, NASA Software Engineering Requirements

NPR 8705.2 Human Rating Requirements and Guidelines for Space Flight Systems

NPR 8715.3, NASA Safety Manual

NPR 8715.x, NASA Range Safety Program **(TBD-65)**

NASA STD 8719.13, Software Safety NASA Technical Standards

NASA-STD-3000, Vol. I, Sections **(TBD-2)**, 5.3 **(TBR-72)** & 8.0 **(TBR-75)**, Man-Systems Integration Standards

Constellation Systems Interface Requirements Document (IRD) **(TBD-66)**

Crew Transportation System (CTS) IRD **(TBD-100)**

CTS / In-Space Support System IRD **(TBD-68)**

CTS / Cargo Delivery System IRD **(TBD-69)**

CTS / Ground Support System IRD **(TBD-67)**

CTS / Destination Surface System IRD **(TBD-70)**

Crew Exploration Vehicle Launch Segment (CEVLS) IRD **(TBD-87)**

2.1.2 Non-Government Documents

Reserved

2.2 Reference Documents

2.2.1 Government Documents

ESMD-RQ-0005, Lunar Architecture Focused Trade Study Final Report
ESMD-RQ-0006, Lunar Architecture Broad Trade Study Final Report
ESMD-RQ-0016, STTP-2 Meeting Minutes
ESMD-RQ-0018, Draft Polar Lunar Landing Site Rationale
ISBN 0-309-07031, Astronomy and Astrophysics in the New Millennium, National Academies of Science
NASA-STD-3000, Vol. I-IV, Man-Systems Integration Standards
NPR 1000.2, NASA Strategic Management Handbook
NPD 1050.1G, Authority to Enter into Space Act Agreements
NPD 1080.1A, NASA Science Policy
NPD 1200.1B, Internal Management Controls and Audit Liaison
NPD 1280.1, NASA Management System Policy
NPD 1360.2A, Initiation and Development of International Cooperation in Space and Aeronautics Programs, NPD 1360.2A
NPR 1385.1, Public Appearances of NASA Astronauts and Other Personnel
NPD 1387.1E, NASA Exhibits Program
NPR 1387.1, NASA Exhibits Program
NPD 1387.2F, Use, Control, and Loan of Lunar Samples for Public and Educational Purposes
NPD 1600.2C, NASA Security Policy
NPR 1620.1A, Security Procedural Requirements
NPR 1800.1, NASA Occupational Health Program Procedures
NPR 1800.2B, NASA Occupational Health Program
NPD 1810.2, NASA Occupational Medicine Program
NPD 1820.1B, NASA Environmental Health Program
NPD 2200.1, Management of NASA Scientific and Technical Information (STI)
NPR 2200.2A, Requirements for Documentation, Approval, and Distribution of NASA Scientific and Technical Information (STI)
NPD 2800.1, Managing Information Technology
NPR 2800.1, Managing Information Technology
NPD 2810.1C, NASA Information Security Policy
NPR 2810.1, Security of Information Technology
NPD 2820.1A, NASA Software Policies
NPD 3310.1A, Distinguishing between Contractor and Civil Service Functions
NPD 5101.32B, Procurement

NPR 5600.2B, Statement of Work (SOW); Guidance for Writing Work Statements
NPR 6000.1F, Requirements for Packaging, Handling, and Transportation for Aeronautical and Space Systems, Equipment, and Associated Components
NPD 7100.10D, Curation of Extraterrestrial Materials
NPD 7120.4B, Program/Project Management
NPR 7120.5B, NASA Program and Project Management Processes and Requirements Approval Authorities for Facility Projects. NPD 7330.1F, Approval Authority for Facility Projects
NPD 7500.1A, Program and Project Logistics Policy
NPR 7500.1, NASA Technology Commercialization Process
NPR 8000.4, Risk Management Procedural Requirements
NPD 8020.7F Biological Contamination Control for Outbound and Inbound Planetary Spacecraft NPD 8020.7F
NPR 3020.12B, Planetary Protection Provisions for Robotic Extraterrestrial Missions
NPD 8610.7A, Launch Services Risk Mitigation Policy for NASA -Owned Or NASA -Sponsored Payloads
NPD 8610.23A, Technical Oversight of Expendable Launch Vehicle (ELV) Launch Services
NPD 8610.24A, Expendable Launch Vehicle (ELV) Launch Services Pre-launch Readiness Reviews
NPD 8700.1B, NASA Policy for Safety and Mission Success
NPD 8700.2A, NASA Policy for Safety and Mission Assurance (SMA) for Experimental Aerospace Vehicles (EAV)
NPD 8700.3A, Safety and Mission Assurance (SMA) Policy for NASA Spacecraft, Instruments, and Launch Services
NPR 8705.3, Safety and Mission Assurance (SMA) Requirements for Experimental Aerospace Vehicles (EAV)
NPR 8705.4, Risk Classification for NASA Payloads
NPR 8705.5, Probabilistic Risk Assessment (PRA) Procedures for NASA Programs and Projects
NPD 8710.3, NASA Policy for Limiting Orbital Debris Generation
NPR 8715.1, NASA Safety and Health Handbook Occupational Safety and Health Programs
NPD 8720.1B, NASA Reliability and Maintainability (R&M) Program Policy
NPD 8730.2B, NASA Parts Policy
NPD 8730.4A, Software Independent Verification and Validation (IV&V) Policy
NPR 8735.2, Management of Government Safety and Mission Assurance Surveillance Functions for NASA Contracts
NPD 8820.2A, Design and Construction of Facilities
NPR 8820.2E, Facility Project Implementation Guide
NPD 8820.3, Facility Sustainable Design
NPD 8900.1F, Medical Operations Responsibilities in Support of Human Space Flight Programs
NPD 9501.1G, NASA Contractor Financial Management Reporting System
NPR 9501.2D, NASA Contractor Financial Management Reporting
NPD 9501.3A, Earned Value Management
NPR 9501.3, Earned Value Management Implementation on NASA Contracts

2.2.2 Non-Government Documents

Reserved

3 Crew Transportation System (CTS) Requirements

The following text does provide, nor represent specific requirements, but is provided as context for the requirements that follow, beginning in section 3.1.

System Description
The Vision for Space Exploration requires NASA to implement an effective and exciting program of exploration and discovery. Sustained and affordable human and robotic missions will extend the human presence across the solar system. Innovative technologies, knowledge, and infrastructures will need to be developed. Over the next two decades, NASA plans to develop a number of new capabilities and systems that are critical to enabling safe and successful human and robotic missions. Vehicle elements to be fielded within this System of Systems will use a “spiral development” approach. In spiral development, the detailed end-state requirements are not known at program initiation. Requirements are refined through system development and demonstration, risk management and continuous user feedback. This approach will build on the experience gained in early Exploration Spirals, to provide flexibility in responding to scientific discoveries and to incorporate new technologies. Robotic Precursor Missions to the Moon and Mars will provide information necessary to conduct future human exploration (i.e., topography mapping, gravity maps, resource identification). In addition, Robotic Precursor Missions will serve as opportunities for advanced technology demonstrations.

Exploration Spiral 1/Crew Exploration Development and Test
Exploration Spiral 1 will establish the capability to test and checkout Crew Transportation System (CTS) elements in Low Earth Orbit (LEO) in preparation for future human exploration missions to the Moon. The capabilities necessary to satisfy the Spiral 1 objectives consist of a Crew Exploration Vehicle (CEV), a Crew Launch Vehicle (CLV), and ground support infrastructure. The CEV and CLV will safely transport the crew from the surface of the Earth to LEO, and return them to the Earth’s surface at the completion of the mission. Demonstration of CEV and launch system performance are critical to enabling Spiral 1 objectives of safe transportation of the crew. Successive demonstrations of the CEV and launch system (including the ability to perform ascent and entry aborts) will begin with a series of risk reduction flight tests, and lead up to crewed CEV operational capability to support human exploration missions beyond LEO. The CEV must have a high degree of automated control to accomplish the early un-crewed test flights. Other CEV flights will test the automated rendezvous and docking systems, to develop the skills and techniques that will be needed for follow-on exploration missions. As exploration capabilities necessary for future spirals are developed, they will be tested with the CEV in the space environment to prepare for future exploration missions. Robotic exploration missions during Spiral 1 will investigate the lunar environment and provide the needed information to prepare for safe landings and human exploration of the lunar surface.

<u>Spiral 1 Flight Hardware Functional Descriptions:</u>
Crew Launch Vehicle:

Will provide the propulsive force necessary to launch the CEV into LEO.

Crew Exploration Vehicle:

Will provide the necessary crew habitation functions during ascent and entry, including mission aborts. Will also provide all maneuvering capability during orbit operations and entry (including aborts).

Robotic Precursor System:
Will provide measurements, technology demonstrations, and may provide infrastructure in advance of human missions.

Ground Support System:
Ground based facilities and capabilities will provide the ability to plan, train, process, launch, operate flight systems, as well as land, recover, refurbish or dispose of those systems.

Exploration Spiral 2/Global Lunar Access for Human Exploration
Exploration Spiral 2 will establish the capability to conduct human exploration missions to any location on the surface of the Moon without pre-positioned surface infrastructure. This Spiral 2 capability will likely be utilized to conduct human exploration of potential lunar base sites prior to the delivery of habitats and surface power systems (Destination Surface Systems). This capability could also be utilized to place humans at the lunar base camp location for habitat and surface power systems final assembly tasks. Once the lunar base is established, this Spiral 2 capability could be utilized to explore locations which are not accessible via surface mobility assets. The systems necessary to satisfy Spiral 2 objectives consist of those developed in Exploration Spiral 1, or derivatives of those capabilities, plus Earth Departure Stage(s) (EDS) necessary to transport elements to the lunar vicinity as well as the Lunar Surface Access Module (LSAM) that will provide the capability for the crew to access the lunar surface. The Cargo Delivery System will deliver un-crewed elements of the Crew Transportation System into LEO and/or lunar orbit (e.g., EDS). Spiral 2 will include successive flight tests to demonstrate the flight characteristics of the CEV, EDS, and LSAM to gain knowledge of how the systems perform at greater distances from Earth and increasing levels of autonomy. Focused robotic precursor technology demonstration missions to Mars are also anticipated within this Spiral.

<u>Spiral 2 Flight Hardware Functional Descriptions:</u>
Crew Launch Vehicle:

Will provide the necessary propulsive force to launch the CEV and other mission elements into LEO.

Crew Exploration Vehicle:

Will provide the necessary crew habitation functions from launch to lunar orbit and return to the Earth surface, including aborts during Earth ascent. The CEV will also provide the necessary propulsive accelerations to return the mission crew from lunar orbit, independent of orbital alignment, for direct entry at Earth. The CEV will rendezvous and dock with other mission elements, such as the EDS and LSAM, in both LEO and lunar orbit. In addition, the CEV will operate un-crewed in lunar orbit while the crew is on the surface of the Moon.

Earth Departure Stage(s):

Will provide the necessary propulsive accelerations needed to transfer the various flight elements (CEV and LSAM) from LEO to lunar orbit, and provide the deceleration for lunar orbit insertion.

Lunar Surface Access Module:

Will provide the necessary crew habitation and transportation functions from lunar orbit to the lunar surface and during return to lunar orbit; will provide crew habitation during lunar surface operations. In addition, the LSAM will provide the capability for the crew to conduct science and perform routine Extra-Vehicular Activity (EVA) on the surface of the Moon.

Cargo Delivery System:

Will deliver un-crewed elements of the CTS into LEO and/or lunar orbit. CDS elements include the Cargo Launch Vehicle and the EDS.

Robotic Precursor System:
Will provide measurements, technology demonstrations, and may provide infrastructure in advance of human missions.

Ground Support System:
Ground based facilities and capabilities will provide the ability to plan, test, train, process, launch, operate flight systems, as well as land, recover, refurbish or dispose of those systems.

Exploration Spiral 3/Lunar Base and Mars Testbed
Exploration Spiral 3 will establish the capability to conduct routine human long-duration missions at a lunar base to test out technologies and operational techniques for expanding the human presence to Mars and beyond. Missions in Spiral 3 will extend up to several months in duration at the lunar poles or equatorial region in order to serve as an operational analog of future Mars missions. Spiral 3 will require the development and deployment of habitats and surface power systems. These Destination Surface Systems (DSS) will be delivered to a selected location in the polar or equatorial region by the Cargo Delivery System (CDS). The number, type, and sequencing of these CDS missions have not yet been specifically defined. Once the surface systems are in place, successively longer missions will be conducted to increase the understanding of system technical performance (including health and human systems), and to provide increasing levels of operational autonomy capabilities that will be necessary for future human Mars exploration missions. The Spiral 2 capability for global access is retained in Spiral 3, and will allow exploration missions to locations not accessible from the base camp via surface mobility assets.

<u>Spiral 3 Flight Hardware Functional Descriptions:</u>
Crew Launch Vehicle:

Will provide the necessary propulsive force to launch the CEV and other mission elements into LEO.

Crew Exploration Vehicle:

Will provide the necessary crew habitation and health maintenance functions from launch to lunar orbit and return to the Earth surface, including aborts during Earth ascent. The CEV also will provide the necessary propulsive accelerations to return the mission crew from lunar orbit, independent of orbital alignment, for direct entry at Earth. The CEV will rendezvous and dock with other mission elements, such as the EDS and LSAM, in both LEO and lunar orbit. In addition, the CEV will operate un-crewed in lunar orbit while the crew is on the surface of the Moon.

Earth Departure Stage(s):

Will provide the necessary propulsive accelerations needed to transfer the various flight elements (CEV, LSAM, and cargo vehicles) from LEO to lunar orbit and provide the deceleration for lunar orbit insertion.

Lunar Surface Access Module:

Will provide the necessary crew habitation and transportation functions from lunar orbit to the lunar surface, and return to lunar orbit. In addition, the LSAM will provide the capability for the crew to perform EVA on the surface of the Moon in order to transition to the surface elements for the long duration missions. The LSAM will remain on the surface of the Moon during the long-duration surface missions.

Cargo Delivery System:

Will deliver un-crewed elements of the Crew Transportation System into Low Earth Orbit and/or lunar orbit. CDS elements include the Cargo Launch Vehicle and the EDS. The CDS will also deliver elements of the DSS from a low lunar orbit to the desired location on the surface of the Moon. The CDS elements have not been completely identified at this time, but should include a Cargo Launch Vehicle, Cargo Destination Landing System, and the EDS.

Destination Surface System:

Will provide crew support capabilities to enable long-duration surface missions. The elements that comprise this system have not been completely defined at this point, but will provide functionality including habitation, communication, power, extended range mobility, enhanced science capabilities, etc. DSS will provide the capability for the crew to conduct long-duration surface science, and perform EVA on the surface of the Moon.

Robotic Precursor System:
Will provide measurements, technology demonstrations, and may provide infrastructure in advance of human missions.

Ground Support System:
Ground based facilities and capabilities will provide the ability to plan, test, train, process, launch, operate flight systems, as well as land, recover, refurbish or dispose of those systems.

3.1 Mission Definition

CTS0430G The CTS shall transport crew from Earth to explore any designated location on the lunar surface and return them to Earth.

Rationale : Sets global access capability for lunar exploration in Spirals 2 and 3. Global access allows flexibility for exploration and keeps multiple options open for the lunar base location. The exploration campaign could require human missions to potential locations of the lunar base prior to the landing of a habitat and other surface infrastructure. Flow-down of Exploration System of Systems requirement.

CTS0017G The CTS shall provide the capability to conduct missions with 1, 2, 3, and 4 crew members (threshold) **(TBR-14)**, with an objective of 5 and 6 crew members **(TBR-15)**.

Rationale : The number of crew required is driven by the expected tasks that must be performed, the skill mix of the mission crews, and the time and frequency provided to conduct the tasks. Studies have shown that a crew size of 4 provides greater mission flexibility and skill mix for the variety of tasks to be performed on the surface of the Moon. The number of crew required is driven by the expected tasks that must be performed, the skill mix of the mission crews, and the time and frequency provided to conduct the tasks. Studies have shown that a crew size of four provides the minimum mission flexibility and skill mix for the variety of tasks to be performed on the surface of the Moon during a long duration mission. A 4 person crew allows 2 EVA teams (2 crew per team) to operate simultaneously or in series with the capability to provide for operational assistance from the non-EVA crew. A 4 person crew is the minimum number required to demonstrate operations concepts for exploring more distant destinations such as Mars. A 6 person crew (objective) represents the most likely Mars exploration crew size, based on previous studies. However, since the human rated launch capability is likely to be significant factor in CEV capability, the 6 person crew size is carried as an objective only. Note: Under Section 3.4.2, Crew Survival, there is a requirement (CTS0405G) that requires CTS capability to conduct a contingency mission with 0 crew.

References: ESMD-RQ-0005, “Lunar Architecture Focused Trade Study Final Results”, ESMD-RQ-0006, “Lunar Architecture Broad Trade Study Final Results”, ESMD-RQ-0015, “STTP-1 Meeting Minutes”, ESMD-RQ-0016, “STTP-2 Meeting Minutes.”

TBR-14 and TBR-15 Closures: Further surface scenario assessments are required during the CE&R study phase. Issue to be resolved no later than 90 days prior to the CEV SRR.

CTS0450G The CTS shall provide a surface mission duration of 4 days (threshold) **(TBR-2)** for crew exploration at any designated location on the moon, with an objective of 7 days **(TBD-78)**.

Rationale : The CTS will provide global access exploration capability without reliance upon additional surface systems. This means that the CTS will be required to provide everything needed to support the crew on the lunar surface (habitation, communication, EVA, etc.). Analysis indicates that a 4 - 7 day lunar-global access capability will be bounded by the lander capability in the equatorial region, and by return to Earth plane change requirements at mid latitudes. 4 days provides a reasonable amount of exploration time for scouting missions, final assembly of Destination Surface Systems (habitats, power systems, etc.) and access to regions away from the lunar base (in spiral 3). Also, this requirement does not imply the ability to go anywhere on the Moon at any time. Thermal constraints on a system designed for polar missions may restrict when a given non-polar mission can be conducted. However, the capability for humans to explore any area of exploration interest on the lunar surface is provided in this Spiral.

References: ESMD-RQ-0005, “Lunar Architecture Focused Trade Study Final Results.”

TBD-78 and TBR-2 Closure: This capability is driven primarily by anytime return and will be established during the CE&R studies. This issue will be resolved no later than 90 days prior to the CEV SRR.

CTS0470G The CTS shall provide the capability to conduct lunar surface EVAs with all crew members.

Rationale : The 4-7 day exploration capability provided by the CTS, requires that the CTS lunar lander provide the capability to perform EVA with all crew members. This requirement does not exclude an airlock capability in the lunar lander, rather it defers that decision until the development of that system/element.

References: ESMD-RQ-0016, “STTP-2 Meeting Minutes.”

CTS0480G The CTS shall provide **(TBD-20)** hours of lunar surface EVA capability per crew member.

Rationale : The CTS must provide EVA capability for global access exploration. The amount of EVA time per crew member must be specified based on exploration tasks.

References: ESMD-RQ-0016, “STTP-2 Meeting Minutes.”

TBD-20 Closure: Closure of this item will be achieved as part of further lunar lander analysis as well as the CE&R studies. Issue to be resolved no later than TBD.

CTS0485G The CTS shall provide **(TBD-21)** lunar surface EVA excursions per mission.

Rationale : The CTS must provide EVA capability for global access exploration. The amount of EVA time per crew member must be specified based on exploration tasks. This requirement sets the total number of depress/repress cycles for the lander.

TBD-21 Closure: Closure of this item will be achieved as part of further lunar lander analysis as well as the CE&R studies. Issue to be resolved no later than TBD.

CTS0490G The CTS shall provide **TBD** accommodations for science capability on the lunar surface **(TBD-24)**.

Rationale : This requirement is a flow-down from Level 0 Exploration Requirement (1.3): “NASA shall conduct human lunar expeditions to further science, and to develop and test new exploration approaches, technologies, and systems, including the use of lunar and other space resources to support sustained human space exploration to Mars and other destinations." The global access exploration capability provided by the CTS must accommodate some level of science capability, although it is expected that the majority of science will be conducted during long duration missions at the lunar base.

TBD Closure: Closure of this item will be achieved as part of further lunar lander analysis as well as the CE&R studies. Further dialogue with the science community is required. Issue to be resolved no later than TBD.

CTS0500G The CTS shall deliver 500 kg of payload (threshold) **(TBR-27)**, with an objective of **(TBD-79)** kg to the lunar surface.

Rationale : This requirement is a flow down from Level 0 Exploration Requirement (1.3): "NASA shall conduct human lunar expeditions to further science, and to develop and test new exploration approaches, technologies, and systems, including the use of lunar and other space resources to support sustained human space exploration to Mars and other destinations." Payload includes science equipment, enhanced mobility equipment, etc. This requirement will be specified in greater detail (e.g., shirtsleeve environment mass) in a future Payload ICD.

References: ESMD-RQ-0005, "Lunar Architecture Focused Trade Study Final Results," ESMD-RQ-0006, "Lunar Architecture Broad Trade Study Final Results."

TBD-79 and TBR-27 Closures: Closure of this item will be achieved as part of further lunar lander analysis as well as the CE&R and CEV Phase II studies. Further dialogue with the science community is required. Issue to be resolved no later than 90 days prior to the CEV SRR.

CTS0510G The CTS shall deliver **(TBD-28)** cubic meters of payload (threshold), with an objective of **(TBD-5)** cubic meters, to the lunar surface.

Rationale : This requirement is a flow-down from Level 0 Exploration Requirement (1.3): "NASA shall conduct human lunar expeditions to further science, and to develop and test new exploration approaches, technologies, and systems, including the use of lunar and other space resources to support sustained human space exploration to Mars and other destinations." Payload includes science equipment, enhanced mobility equipment, etc. Further definition of detailed surface strategy for lunar surface missions is required. Pressurized and unpressurized payload volume (as well as other payload accommodations) will be specified at a lower level of requirements.

TBD-28 and TBD-5 Closures: Closure of this item will be achieved as part of further lunar lander analysis as well as the CE&R and CEV Phase II studies. Further dialogue with the science community is required. Issue to be resolved no later than 90 days prior to the CEV SRR.

CTS0520G The CTS shall return 100 kg (threshold) **(TBR-25)** of payload, with an objective of **(TBD-80)** kg to Earth.

Rationale : This requirement is a flow down from Level 0 Exploration Requirement (1.3): "NASA shall conduct human lunar expeditions to further science, and to develop and test new exploration approaches, technologies, and systems, including the use of lunar and other space resources to support sustained human space exploration to Mars and other destinations." Although it may be viewed as a design solution, it is likely that it will be impossible to carry all the laboratory equipment necessary to adequately analyze all the lunar surface materials of interest. It is likely a set of surface-deployed experiments will be left on the surface of the moon, and that will allow comparable mass for lunar sample return. 100 kg return capability is being used until surface strategies are further defined.

References: ESMD-RQ-0005, "Lunar Architecture Focused Trade Study Final Results," ESMD-RQ-0006, "Lunar Architecture Broad Trade Study Final Results."

TBD-80 and TBR-25 Closures: Closure of this item will be achieved as part of further lunar lander analysis as well as the CE&R and CEV Phase II studies. Further dialogue with the science community is required. Issue to be resolved no later than 90 days prior to the CEV SRR.

CTS0330G The CTS shall return **(TBD-26)** cubic meters of payload (threshold), with an objective of **(TBD-81)** cubic meters , to Earth.

Rationale : This requirement is a flow-down from Level 0 Exploration Requirement (1.3): "NASA shall conduct human lunar expeditions to further science, and to develop and test new exploration approaches, technologies, and systems, including the use of lunar and other space resources to support sustained human space exploration to Mars and other destinations." Although it may be viewed as a design solution, it is likely that it will be impossible to carry all the laboratory equipment necessary to adequately analyze all the lunar surface materials of interest. It is likely that a set of surface-deployed experiments will be left on the surface of the moon, and that will allow comparable volume for lunar sample return.

TBD-26 and TBD-81 Closures: Closure of this item will be achieved as part of further lunar lander analysis as well as the CE&R and CEV Phase II studies. Further dialogue with the science community is required. Issue to be resolved no later than 90 days prior to the CEV SRR.

3.2 Mission Success

CTS0030H The CTS shall provide single failure tolerance to loss of mission and critical hazards, except where the CTS meets NASA approved "Design for Minimum Risk" Criteria.

Rationale : This requirement establishes the failure tolerance design criteria for the system against the loss of successful mission completion, non-life-threatening injuries, or significant damage to the system. NASA Procedural Requirement (NPR) 8705.2 has failure tolerance criteria to prevent loss of life, however it does not provide measures to preclude loss of other mission assets. Although aborts and crew escape systems help to ensure survival of the crew and other personnel, loss of high value hardware and the additional risk of relaunching the crew could jeopardize completion of a mission. This requirement ensures robustness is built into the system through tolerance to failures. The Exploration System of Systems Programmatic Requirements detail the "Design for Minimum Risk" Criteria.

CTS0040G The CTS availability shall support CTS mission element assembly and Earth orbit departure constraints.

Rationale : Launch availability is a metric representing the likelihood that a given launch will be achieved within the allocated mission timeline. Launch Availability is composed of four elements: 1) System Availability- a metric indicating the likelihood that the facility throughput capability and CTS hardware is acceptable for launch; 2) Natural Environment Constraints - a metric reflecting the likelihood that the CEVLS will be able to fly safely with respect to the natural environment (such as upper level winds); 3) Acceptable Launch Site Weather - Probability that launch vehicle or range weather constraints (typically everything except upper level winds) will not be violated; and 4) Acceptable Abort Weather - Probability that abort site weather constraints will not be violated. Because many of the proposed exploration initiative scenarios involve multiple element launches over a relatively short period of time (typically two weeks), it is expected that the CTS will require high Launch Availability.

3.3 Performance Characteristics

CTS0295G Docking of CTS elements in Earth orbit shall be performed in the Earth Reference Orbit.

Rationale : Lunar missions will require the docking of elements in Earth orbit prior to departure for the Moon. This orbit must be defined at the system level for subsequent allocation to each element's requirement set. Launches into 28.5 degree inclination orbits allow the maximum payload to orbit from the Eastern Range, while allowing launches from other locations at lower latitudes. The assembly altitude is specified to minimize the effects of atmospheric drag on orbital lifetime and provide repeating ground-tracks useful in achieving a consistent daily phase window.

Reference: ESMD-RQ-0017, "Orbital Characteristics Required for Rendezvous and Assembly of Exploration Initiative Elements".

CTS0297G Transit of CTS elements from the Earth Reference Orbit to the Lunar Reference Orbit shall take no longer than 5 days **(TBR-26)**.

Rationale : Maximum transit time specified to allow sizing of CTS elements. Also, minimizes crew deconditioning prior to arrival at the destination.

Reference: ESMD-RQ-0017, "Orbital Characteristics Required for Rendezvous and Assembly of Exploration Initiative Elements".

TBR-26 Closure:

CTS0301G Rendezvous and docking of CTS elements in Lunar orbit enroute to the lunar surface shall be accomplished by inserting the active element (chaser) into the Initial Lunar Phasing Orbit. **(TBR-24)**

Rationale : Potential architectures under consideration have elements such as the CEV and LSAM in transit to the Moon separately. The chaser element (e.g., CEV) is placed into a phasing orbit in order to initiate rendezvous with the target vehicle (e.g., LSAM). Separate elements such as the EDS provide the propulsion required to transport these elements to Lunar orbit. Therefore, it is necessary to establish the Initial Lunar Phasing Orbit (defined in the glossary) at the system level for elements requiring lunar orbit rendezvous for subsequent allocation to each element's requirement set.

Reference: ESMD-RQ-0005, Lunar Architecture Focused Trade Study Final Results”.

TBR-24 Closure: Rendezvous in lunar orbit enroute is under review. Closure 90 days prior to SRR.

CTS0070G Docking of CTS elements in lunar orbit enroute to the lunar surface shall be performed in the Lunar Reference Orbit. **(TBR-23)**

Rationale : Potential architectures under consideration include those that require docking of elements in lunar orbit. The Lunar Reference Orbit is established at the system level (and the defined in the glossary) for subsequent allocation to each element’s requirement set. Orbital inclination is a polar orbit for landing sites in the polar region, and is optimized to minimize the required plane changes for non-polar region landing site locations (inclination is varied based on planned mission duration).

Reference: ESMD-RQ-0005, Lunar Architecture Focused Trade Study Final Results”, ESMD-RQ-0015, “STTP-1 Meeting Minutes”.

TBR-23 Closure: Docking in lunar orbit enroute is under review. Closure 90 days prior to SRR.

CTS0340G The CTS shall transport the crew to the lunar surface within **(TBD-18)** meters (threshold) of a designated location, with an objective of **(TBD-82)** meters.

Rationale : The intent is to have the capability to land near a designated area of scientific and exploration interest or to land near a pre-positioned asset such as a habitat.

TBD-18 and TBD-82 Closures: Closure of this item will occur after additional analysis of landing accuracy needs, prior to baselining the LSAM requirements.

CTS0100G Docking of CTS elements in lunar orbit upon return from the lunar surface shall be performed in the Lunar Ascent Orbit.

Rationale : Potential architectures under consideration include a rendezvous in lunar orbit after the crew leaves the lunar surface. The maximum wedge angle that must be accommodated by either the CEV or a LSAM must be specified at the system level. Ten degrees of wedge angle covers missions to the Polar Regions of the Moon (see glossary for definition of Polar Regions of the Moon, and Lunar Ascent Orbit parameters) of any duration, and approximately 7 days of “global access” mission duration. Thus, there is a synergy between the capability of the CEV and LSAM for global access missions away from the lunar base and long-duration lunar missions at the lunar base.

Reference: ESMD-RQ-0005, "Lunar Architecture Focused Trade Study Final Results”, ESMD-RQ-0015, “STTP-1 Meeting Minutes”.

CTS0050H The CTS shall provide the capability to monitor, command, and control the system segments and elements.

Rationale : This requirement serves as the parent for lower level requirements which will specify command and control by mission control and the crew. Mission success and the safety of the flight crew, ground personnel and the general public will be dependent on the ability of the CTS to monitor, command and control the system, segments, and mission elements. One example is the capability required for public safety and the ability of the Range Safety System to track launch vehicle trajectory and performance and issue flight termination commands if required. Another example is the ability to detect and annunciate mission and safety critical conditions, isolate the conditions, and provide for recovery of mission and safety critical functions.

CTS0075H The CTS shall provide automated control linked to the mission phase and function.

Rationale : A high degree of automation is desired for the CTS to minimize the number of routine tasks required of the crew and mission control personnel. The cost of automation must be balanced against development cost, schedule, and technical risk. This requirement is a broadly defined parent for lower-level requirements that will specify levels of automation.

CTS0300H The CTS shall provide autonomous operations linked to the mission phase and function with an objective of autonomous operations throughout the mission.

Rationale : A high degree of CTS autonomy is desired for the CTS. Autonomy is required for functions for which there is not reasonable time for response from mission control. A defined methodology should be applied to each mission phase and vehicle function to determine how much autonomy is needed, and to assess where it is cost effective. This requirement serves as a broadly defined parent for lower level requirements that will specify the level of autonomy.

CTS0320H The CTS shall provide manual intervention of automated functions critical to mission success and crew safety.

Rationale : Manual intervention of automated control can be executed by ground control personnel or the crew. Human intervention capability is required to ensure that automated functions do not perform actions that are inappropriate in a particular failure scenario. For example, previous system or sensor failures may make an automated response undesirable. The requirement specifically does not say "all automated functions" - that determination is left to the program. Crew intervention requirements are covered in NPR 8705.2.

3.3.1 Operations

CTS0090H The CTS shall provide consumables margins to protect for delays in executing critical mission events.

Rationale : Reserve margins are needed to allow for unplanned events that cause mission extension beyond the originally planned duration. This will drive consumables levels and sizing for the vehicles. Consumables include propellant (for Delta-V and attitude control), power, habitation, and crew consumables. This requirement specifically does not specify all critical events - lower level requirements will specify events to be covered. This requirement will serve as the parent requirement to trace specific contingency capability requirement for each element.

3.3.2 Flight Control (Reserved)

3.3.3 Communications (Reserved)

3.3.4 Crew Environment

CTS0115H The CTS shall limit accelerations and rotational rates on the crew in accordance with NASA Standard 3000, Volume I, Section 5.3 **(TBR-72)**.

Rationale : Axial and rotational acceleration rates imparted to the crew must be limited to acceptable levels to safely transport the crew. The acceptable acceleration rates are documented in NASA STD 3000.

TBR-72 Closure: NASA STD 3000 does not currently account for acceleration rates required to preserve crew life in the event of an abort or escape. Updates to NASA STD 3000 are required prior to CEV Request for Proposals (RFP) release.

CTS0116H The CTS shall provide the net habitable volume necessary for simultaneous crew activities as required by the mission phase.

Rationale : The necessary habitable volume is dependent on required crew activities. Simultaneous crew operations are required so that a critical activity is not interrupted by the need to perform another time critical activity. Examples of crew activities include trajectory monitoring and control, systems management, suit doffing and donning, waste management, etc.

CTS0117H The CTS net habitable volumes shall comply with the requirements in NASA Standard 3000, Volume I, Section 8 **(TBD-2)**.

Rationale : NASA 3000 sets the minimum habitable volume based on mission duration.

TBD-2 Closure: Updates to NASA Std 3000 are required prior to RFP release. If not updated, delete requirement.

CTS0238H The CTS habitable environments shall be maintained in accordance with the Constellation Systems IRD **(TBD-66)**.

Rationale : The CTS will likely have multiple habitable elements with common environments. The environmental standards (such as pressure, percentage oxygen, temperature, humidity, etc.) must be specified at the Constellation Systems level. The CEV is the first element that will comply with this interface document.

TBD-66 Closure: This IRD must be developed by Constellation Systems, in coordination with the ESMD Requirements Division.

3.3.5 Software

CTS0270H The CTS shall comply with NPR 7150, NASA Software Engineering Requirements.

Rationale : NPRs are agency level requirements and not at the discretion of the Directorate.

3.4 Safety

3.4.1 General

CTS0140H The CTS shall comply with NPR 8705.2, Human Rating Requirements and Guidelines for Space Flight Systems.

Rationale : NPRs are Agency level requirements and not at the discretion of the Directorate.
In order to fly humans in space, each element of the System of Systems that interfaces with the crew is required to be certified as human-rated. NPR 8705.2 delineates the requirements and process for obtaining that certification and is applicable to those elements that interact with the crew.
The current version is NPR 8705.2, with Change 2 dated 6/25/04. The document is currently under review and a new, approved version is expected prior to release of the CEV RFP.

CTS0150H The CTS shall comply with NPR 8715.3, NASA Safety Manual.

Rationale : NPRs are Agency level requirements and not at the discretion of the Directorate.
This document contains the requirements and procedures that define the NASA Safety Program for minimizing the risk to personnel and equipment.

CTS0160H The CTS shall comply with NASA STD 8719.13, Software Safety Standard, for all Safety-Critical Software.

Rationale : Software is a critical component of all complex space systems. Safety Critical Software (as defined in NASA-STD-8719.13) must be developed and tested to ensure the safety of the crew. Although 8719.13 is a standards document, it contains specific software requirements.

CTS0170H The CTS, when launching from U.S. Ranges, shall comply with NPR 8715.X **(TBD-65)**, NASA Range Safety Program.

Rationale : NPRs are Agency level requirements and not at the discretion of the Directorate. Space systems launched from US ranges are required to comply with Air Force Range Requirements as tailored for the system. The Range Safety NPR will contain the NASA tailored requirements to launch from US Ranges.

TBD-65 Closure: The NPR is currently in the NASA Online Directive Information System (NODIS) review cycle, with OSMA responsibility. Completion is expected in early 2005.

3.4.2 Crew Survival

CTS0180H The CTS shall provide dual failure tolerance to catastrophic hazards, including permanent disability or loss of life, except where the CTS meets NASA approved "Design for Minimum Risk" criteria.

Rationale : This requirement establishes the failure tolerance design criteria for the system against all types of catastrophic hazards. NPR 8705.2 has failure tolerance criteria to prevent loss of life and permanent disability, however it does not provide measures to preclude other type of catastrophic hazards, loss of major vehicle segments or major facilities. Failure to mitigate against these hazards puts the crew and personnel at risk, as well as loss of high value strategic assets. The ESS Technical Requirements detail the "Design for Minimum Risk" Criteria (ESMD-RQ-0010).

CTS0405G The CTS shall provide the capability to conduct contingency/rescue missions to lunar orbit and the lunar surface. **(TBR-21)**

Rationale : This functionality provides for rescue of a crew that is stranded, and incapable of return to Earth. This encompasses a crew stranded in lunar orbit, or stranded on the lunar surface. This requirement will be a parent to CTS flight element requirements (CEV, CEVLV, LSAM, and EDS). A combination of automated and remote control of the CTS will be required to satisfy this requirement. This requirement does not mandate the response time for the rescue mission - just the system capability to conduct such a mission.

TBR-21 Closure: 90 days prior to SRR Agency level decision for safety.

CTS0110G The CTS shall provide abort capability from the launch pad on Earth until **(TBD-32)** meters from the lunar surface (threshold), with an objective of abort capability until touchdown on the lunar surface.

Rationale : Early return may be required for any number of emergencies or contingencies and is needed to maximize crew survival.

Reference: ESMD-RQ-0005, "Lunar Architecture Focused Trade Study Final Results".

TBD-32 Closure: Abort capability enroute to the lunar surface will be determined during the development of the LSAM requirements set.

CTS0120G The CTS shall return the crew to Earth, within 6 days **(TBR-20)**, from any location on the surface of the Moon or lunar orbit, at any time during the mission duration, independent of orbital alignment.

Rationale : Early departure from the lunar surface may be required to assure crew survival, due to unforeseen events. This is a driving requirement for CEV sizing. For the polar and equatorial missions, the required mission duration of 42 days (threshold) drives the CTS to accommodate the worst case plane change for Earth return. For missions outside the polar and equatorial regions, the worst case plane change is bounded by the mission duration of 4 days (threshold) and the optimum CEV orbit established for that mission duration.

References: ESMD-RQ-0005, "Lunar Architecture Focused Trade Study Final Results", ESMD-RQ-0015, "STTP-1 Meeting Minutes".

TBR-20 Closure: 90 days prior to SRR.

CTS0125H The CTS shall provide for contingency EVA during operations in Earth orbit. **(TBD-33)**

Rationale : Contingency EVA capability was specifically identified by the Operations Advisory Group (OAG) as a high priority capability.

TBD-33 Closure: TBD applies to the entire requirement and whether this is a required capability. Specific contingency tasks cannot be identified until the CTS elements have been designed. Therefore, this requirement will remain TBD, pending further study.

CTS0130G The CTS shall provide for contingency EVA during Earth-Moon transit and during operation in lunar orbit. **(TBD-34)**

Rationale : Contingency EVA capability was specifically identified by the OAG as a high priority capability.

TBD-34 Closure: TBD applies to the entire requirement and whether this is a required capability. Specific contingency tasks cannot be identified until the CTS elements have been designed. Therefore, this will requirement remain TBD, pending further study.

CTS0220H Upon return to Earth, the CTS shall provide 36 hours **(TBR-35)** of crew survival after landing.

Rationale : The CTS must provide crew survival capability while awaiting rescue. The requirement to rescue the crew following an abort will be part of the Ground Support System requirements. It is possible that for some aborts into the Atlantic Ocean, the first response forces to arrive would provide additional survival equipment until additional forces arrive to recover the crew.

TBR-35 Closure: Closure of this item will be achieved no later than 90 days prior to the CEV System Requirements Review.

3.4.3 Vehicle Health

CTS0190H The CTS shall detect and annunciate conditions which could result in loss of human life, loss of vehicle, loss of mission, or significantly impact mission capability.

Rationale : This requirement captures functionality, such as Integrated Health Management, for the detection of system failures. For situational awareness, the crew and mission control must be aware of significant changes in vehicle status, even if automated systems respond to the condition. This requirement intentionally does not specify all failures - which is not practical. Also, it is left to the program to interpret "significantly impact mission capability" in the lower level requirements. This requirement serves as a parent to flight element health status monitoring requirements.

CTS0200H The CTS shall provide autonomous isolation and recovery, with an objective of automated isolation and recovery, from conditions which could result in loss of human life or loss of vehicle.

Rationale : This requirement captures functionality, such as Integrated Health Management and redundancy management, for the detection and mitigation of system failures. Reliance on communication with mission control to avoid loss of vehicle or loss of life is not acceptable. Automated recovery should be used when practical, and for all cases where the time required for human response will not prevent the loss. The requirement specifically does not say all failures - since this is not practical. It is intentionally left to the program to determine what failures can be isolated and recovered.

A defined methodology should be applied to each mission phase and vehicle function to determine how much automation is needed, and where automation is cost effective. This requirement serves as the parent for lower level requirements that must be established using this approach.

CTS0230H The CTS shall provide isolation and recovery from conditions which could result in loss of mission or significantly impact mission capability.

Rationale : Recovery for failures which could result in loss of crew or vehicle is covered in a separate requirement. This requirement will serve as a parent requirement for lower level implementation of systems (i.e. vehicle health management systems etc.) to ensure that failures which could impact mission success or capability are addressed. This requirement intentionally does not specify all conditions - which is not practical.

CTS0045H The CTS shall capture, archive, and make retrievable, mission and safety critical performance data.

Rationale : The ability to capture mission and safety critical performance data, and archive it in a retrievable format is necessary to support real-time anomaly resolution and post-mission data analysis.

3.5 Interfaces

CTS0240H The CTS shall provide communication in accordance with the Constellation Systems IRD **(TBD-66)**.

Rationale : The complexity of possible architectures and the serial acquisition of exploration elements dictates a standard communications interface between all elements of the Exploration System of Systems. "Communication" includes command, data, voice and video. Constellation Systems must define the standard communications system in an IRD to include bandwidth, rates, security, etc. The CEV and the CEVLS are the first CTS elements that will comply with this interface document.

TBD-66 Closure: This IRD must be developed by Constellation Systems, in coordination with the ESMD Requirements Division.

CTS0250H The CTS interface with the Ground Support System shall comply with the requirements of the CTS / Ground Support System IRD **(TBD-67)**.

Rationale : The CTS will interface with Ground Support Systems such as Mission Control and recovery / rescue forces. The CEV and the CEVLS are the first CTS elements that will comply with this interface document.

TBD-67 Closure: This IRD must be developed by Constellation Systems, in coordination with the ESMD Requirements Division.

CTS0260H The CTS interface with the In-Space Support System shall comply with the requirements of the CTS / In-Space Support System IRD **(TBD-68)**.

Rationale : The CTS will interface with the In-Space support System such as communications satellite systems and navigation satellite systems. The CEV is the first CTS element that will comply with this interface document.

TBD-68 Closure: This IRD must be developed by Constellation Systems, in coordination with the ESMD Requirements Division.

CTS0280G The CTS interface with the Cargo Delivery System shall comply with the requirements of the CTS / Cargo Delivery System IRD **(TBD-69)**.

Rationale : Some CTS elements will be launched by a Cargo Launch Vehicle. Therefore, Constellation Systems must define the CTS and Cargo Delivery interface requirements. The EDS is potentially the first CTS element that will comply with this interface document.

TBD-69 Closure: This IRD must be developed by Constellation Systems, in coordination with the ESMD Requirements Division.

CTS0360G The CTS elements shall dock and undock with other habitable Exploration elements in space using a common docking mechanism and interface in accordance with the Constellation Systems IRD **(TBD-66)**.

Rationale : The acquisition strategy, which develops the CEV within a potential family of architectures, dictates the use of a common docking system for all in-space mating operations. This will allow the CEV to dock to different elements at different times in a given mission profile using the same docking system. Development of this docking system must be a high priority for the Constellation Systems and must be complete in time to support CEV development.

TBD-66 Closure: This IRD must be developed by Constellation Systems, in coordination with the ESMD Requirements Division.

CTS0370G The CTS elements shall rendezvous, dock and undock with other Exploration elements in space using a rendezvous and proximity operations sensor capability in accordance with the Constellation Systems IRD **(TBD-66)**.

Rationale : The acquisition strategy, which develops the CEV within a potential family of architectures, dictates the use of a common sensor package for all in-space docking operations. Since different elements may be mated at different times during a given mission profile, the sensors and targets on each element must be compatible. Development of the sensor package must be complete in time to support CEV development.

TBD-66 Closure: This IRD must be developed by Constellation Systems, in coordination with the ESMD Requirements Division.

CTS0380G When docked to another Exploration element, the CTS elements shall communicate with the other elements in accordance with the Constellation Systems IRD **(TBD-66)**.
Rationale : The NASA human rating requirements dictate extensive crew insight into critical mission events that will be performed by other Exploration elements while docked to the CEV. It is expected that this communication will include data, command, video, voice, fault detection and annunciation. The complexity of possible architectures dictates a standard hardline communications interface between all docked elements of the Exploration System of Systems. The CEV and the EDS are potentially the first CTS elements that will comply with this IRD.

TBD-66 Closure: This IRD must be developed by Constellation Systems, in coordination with the ESMD Requirements Division.

3.6 (Reserved)

3.7 Subordinate Elements

3.7.1 Crew Exploration Vehicle Launch Segment (CEVLS)

3.7.1.1Mission Definition

CVS0010H The CEVLS shall deliver a Crew Exploration Vehicle (CEV) to an Earth Ascent Target Orbit.
Rationale : This is the primary function of the CEVLS. A mission capable CEV must be placed into an orbit from which the CEV is capable of completing the mission. The first mission objective for the CEV will be to rendezvous and dock with the other elements of the CTS. The CEVLS must insert the CEV into an orbit that reflects the navigational accuracy, launch window and orbital characteristics necessary to complete future Exploration missions. The CEVLS should achieve the required orbit with adequate performance margin.

References: ESMD-RQ-0005, “Lunar Architecture Focused Trade Study Final Results”, ESMD-RQ-0006, “Lunar Architecture Broad Trade Study Final Results”, ESMD-RQ-0015, “STTP-1 Meeting Minutes”, ESMD-RQ-0016, “STTP-2 Meeting Minutes.”

CVS0120H The CEVLS shall provide the capability to launch a CEV to the Earth Ascent Target Orbit with 0, 1, 2, 3, and 4 **(TBR-13)** CEV crew members, with an objective of 5 and 6 CEV crew members **(TBR-15)**.

Rationale : The requirement is intentionally written so that the CEVLS will be capable of operating with or without crew. This requirement also specifies the capability to operate with any number of crew less than a full complement; this could have Center of Gravity (CG), configuration, and operational implications.

Capability provides necessary CTS functionality to execute a contingency/crew rescue mission with 0 crew (parent is CTS0405G). Verification of this requirement for the CEV Launch Segment will occur during Spiral 1.

References: ESMD-RQ-0005, “Lunar Architecture Focused Trade Study Final Results”, ESMD-RQ-0006, “Lunar Architecture Broad Trade Study Final Results”, ESMD-RQ-0015, “STTP-1 Meeting Minutes”, ESMD-RQ-0016, “STTP-2 Meeting Minutes.”

TBR-13 and TBR-15 Closure: Additional data to support this requirement will be developed during the CE&R studies. Issue to be resolved no later than 90 days prior to the CEV SRR.

3.7.1.2 Mission Success

CVS0130B The CEVLS shall provide a predicted ascent success probability of 0.99325 **(TBR-44)** at 65% **(TBR-45)** confidence with an objective of 0.99325 **(TBR-46)** at 80% **(TBR-47)** confidence.

Rationale : The threshold ascent success number assures that the CEVLS is at least as good as present day human-rated systems. It is reasonable to expect that the next human launch system should provide an improved, predicted analytical reliability over that of today's system with progressive increases in the level of confidence as the system is operated over a period of several years. The increase in confidence level is evenly divided among the three spirals with an ultimate objective of 95% confidence. To ensure continued advances in system reliability and safety, the objective of a spiral becomes the threshold of the subsequent spiral.

TBR-44, TBR-45, TBR-46 and TBR-47 Closures: The TBRs in this requirement will require Agency-level approval to finalize.

CVS0032H The CEVLS shall provide single failure tolerance to loss of mission and critical hazards, except where the CEVLS meets NASA approved "Design for Minimum Risk" Criteria.

Rationale : This requirement establishes the failure tolerance design criteria for the system against the loss of successful mission completion, non-life-threatening injuries, or significant damage to the system. NPR 8705.2 has failure tolerance criteria to prevent loss of life, however it does not provide measures to preclude loss of other mission assets. Although aborts and crew escape systems help to ensure survival of the system's crew and other personnel, loss of high value hardware and the additional risk of relaunching the crew could jeopardize completion of a mission. This requirement ensures robustness is built into the system through tolerance to failures. The ESS Programmatic Requirements detail the "Design for Minimum Risk" criteria (ESMD-RQ-0010).

CVS0040G The CEVLS launch availability, inclusive of system and environmental factors, shall support CTS mission element assembly and Earth orbit departure constraints.

Rationale : Launch Availability is metric representing the likelihood that a given launch will be achieved within the allocated mission timeline. Launch Availability is composed of four elements: 1) System Availability- a metric indicating the likelihood that the CEVLS hardware is acceptable for launch; 2) Natural environment constraints - a metric reflecting the likelihood that the CEVLS will be able to fly safely with respect to the natural environment (such as upper level winds); 3) Acceptable Launch Site Weather - Probability that launch vehicle or range weather constraints (typically everything except upper level winds) will not be violated; and 4) Acceptable Abort Weather - Probability that abort site weather constraints will not be violated. Because many of the proposed exploration initiative scenarios involve multiple element launches over a relatively short period of time (typically two weeks), it is expected that the CEVLS will require high Launch Availability.

3.7.1.3Performance Characteristics

CVS0050H The CEVLS shall provide the capability to monitor, command, and control the CLV and CEV.

Rationale : Mission success and the safety of the flight crew, ground personnel and the general public will be dependent on the ability of the CEVLS to monitor, command and control CEV and CLV. A critical capability required for public safety is the ability of the Range Safety System to track launch vehicle trajectory and performance and issue flight termination commands if required. Another example is the ability to detect and annunciate mission and safety critical conditions, isolate the conditions, and provide for recovery of mission and safety critical functions.

CVS0060H The CEVLS shall provide automated control of the vehicle from lift off until CEV insertion into the Earth Ascent Target Orbit.

Rationale : Automated control is required during the dynamic launch phase. The launch environment is not conducive to manual crew action to perform operations, and in the dynamic flight phase it is not appropriate to have routine ground control of the vehicle due to the potential for quick response times and possible communications outages.

CVS0080H The CEVLS shall provide automated control of vehicle functions during aborts.

Rationale : Automated control is required during launch segment aborts from automatic detection of the abort condition through landing, including landing site selection. The abort environment is not conducive to manual crew action to perform operations, and in the dynamic flight phase it is not appropriate to have routine ground control of the vehicle due to the potential for quick response times, and possible communications outages.

CVS0090H The CEVLS shall provide manual intervention capability of automated functions critical to mission success and crew safety.

Rationale : Manual intervention of automated control can be executed by ground control or flight crew. Human intervention capability is required to ensure that automated functions do not perform actions that are inappropriate in a particular failure scenario. For example, previous system or sensor failures may make an automated response undesirable. This requirement specifically does not say "all automated functions" - that determination is left to the program. The requirement for manual intervention of functions critical to crew survival is covered in NPR 8705.2.

3.7.1.3.1 Operations

CVS0210H The CEVLS shall be available to support the next CEV launch opportunity following a launch scrub due to weather.

Rationale : The Launch System will require a timely recovery capability from environmental and technical issues to efficiently utilize available launch opportunities and minimize impacts to Exploration system elements. Incorporating robustness into the Launch System will drive redundancy and reliability requirements and technical and consumables margins.

This requirement intentionally does not say all launch scrubs as it is recognized that some technical problems will require more time to resolve. The intent is that the CEVLS design be capable of supporting the next CTS launch opportunity, when the scrub is due to weather or environmental factors. This capability can also be utilized when the scrub is due to a technical failure that is recoverable prior to the next opportunity.

3.7.1.3.2 Flight Control (Reserved)

3.7.1.3.3 Communications (Reserved)

3.7.1.3.4 Crew Environment

CVS0230H The CEVLS shall limit accelerations and rotational rates on the crew in accordance with NASA Standard 3000, Volume I, Section 5.3 **(TBR-72)**.

Rationale : To safely transport the crew, both the axial and rotational acceleration rates imparted to the crew must be limited to acceptable levels. The acceptable acceleration rates are documented in NASA STD 3000.

TBR-72 closure: NASA STD 3000 does not currently account for acceleration rates that may be required to preserve crew life in the event of an abort of an abort or escape. Updates to NASA STD 3000 are required prior to CEV RFP release.

3.7.1.3.5 Software

CVS0240H The CEVLS shall comply with NPR 7150, NASA Software Engineering Requirements.

Rationale : NPRs are agency level requirements and not at the discretion of the Directorate.

3.7.1.4Safety

3.7.1.4.1 General

CVS0250H The CEVLS shall comply with NPR 8705.2, Human Rating Requirements and Guidelines for Space Flight Systems.

Rationale : NPRs are Agency level requirements and not at the discretion of the Directorate.
In order to fly humans in space, each element of the System of Systems that interfaces with the crew is required to be certified as human rated. NPR 8705.2 delineates the requirements and process for obtaining that certification and is applicable to those elements that interact with the crew.
The current version is NPR 8705.2, with Change 2 dated June 25, 2004. The document is currently under review and a new, approved version is expected prior to release of the CEV RFP.

CVS0260H The CEVLS shall comply with NPR 8715.3, NASA Safety Manual.

Rationale : NPRs are Agency level requirements and not at the discretion of the Directorate.
This document contains the requirements and procedures that define the NASA Safety Program for minimizing the risk to personnel and equipment.

CVS0270H The CEVLS shall comply with NASA STD 8719.13, Software Safety Standard, for all Safety-Critical Software.

Rationale : Software is a critical component of all complex space systems. Safety Critical Software (as defined in NASA-STD-8719.13) must be developed and tested to ensure the safety of the crew. Although 8719.13 is a standards document, it contains specific software requirements.

CVS0280H The CEVLS shall comply with NPR 8715.X, NASA Range Safety Program **(TBD-65)**.

Rationale : NPRs are Agency level requirements and not at the discretion of the Directorate.
Space systems launched from US ranges are required to comply with Air Force Range Requirements as tailored for the system. The Range Safety NPR will contain the NASA tailored requirements to launch on US Ranges.

TBD-65 Closure: The NPR is currently in the NODIS review cycle, with OSMA responsibility. Completion is expected in early 2005.

3.7.1.4.2 Crew Survival

CVS0380B The CEVLS shall provide a predicted ascent crew survival probability of 0.999325 **(TBR-52)** at 65% **(TBR-53)** confidence with an objective of 0.999325 **(TBR-54)** at 80% **(TBR-55)** confidence.

Rationale : Space transportation systems require that particular attention be paid to crew survival. The Columbia Accident Investigation Board Report stated, "Significant improvement in Earth-to-orbit crew transportation is required of future systems". Use of abort/escape options will provide significant improvement in crew survival probability over current systems in operation. The increasing confidence level is evenly divided among the first three Exploration Spirals with an ultimate objective of 95% confidence. To ensure continued advances in system reliability and safety, the objective of a given spiral becomes the threshold of the subsequent spiral.

TBR-52, TBR-53, TBR-54 and TBR-55 Closures: The TBRs in this requirement will require Agency-level approval to finalize.

CVS0295H The CEVLS shall provide dual failure tolerance to catastrophic hazards, including permanent disability or loss of life, except where the CEVLS meets NASA approved "Design for Minimum Risk" criteria.

Rationale : This requirement establishes the failure tolerance design criteria for the system against all types of catastrophic hazards. NPR 8705.2 has failure tolerance criteria to prevent loss of life and permanent disability, however it does not provide measures to preclude other type of catastrophic hazards, such as non-debilitating injury, loss of major vehicle segments or major facilities. Failure to mitigate against these hazards puts the crew and personnel at risk, as well loss of high value strategic assets. The ESS Programmatic Requirements detail the "Design for Minimum Risk" criteria (ESMD-RQ-0010).

CVS0320H The CEVLS shall provide abort capability from the time the hatch is closed on the launch pad until the insertion of the CEV into the Earth Ascent Target Orbit.

Rationale : Abort capability throughout ascent has been proven feasible in previous programs. "Abort to orbit” is an acceptable abort provided the CEV has the capability to return safely to Earth following the “Abort to Orbit”. This abort requirement includes all events required to return the crew safely to Earth in the entry spacecraft.

3.7.1.4.3 Vehicle Health

CVS0300H The CEVLS shall detect and annunciate conditions which could result in loss of human life, loss of vehicle, loss of mission, or significantly impact mission capability.

Rationale : This requirement captures functionality, such as Integrated Health Management, for the detection of system failures. For situational awareness, the crew and ground control must be aware of significant changes in vehicle status, even if automated systems respond to the condition. This requirement intentionally does not specify all failures - which is not practical. Also, it is left to the program to interpret "significantly impact mission capability" in the lower level requirements. The requirement serves as a parent to flight element health status monitoring requirements.

CVS0310H The CEVLS shall provide autonomous isolation and recovery, with an objective of automated isolation and recovery, from conditions which could result in loss of human life or loss of vehicle.

Rationale : This requirement captures functionality, such as Integrated Health Management and redundancy management, for the detection and mitigation of system failures. Reliance on communication with mission control to avoid loss of vehicle or loss of life is not acceptable. Automated recovery should be used when practical, and for all cases where the time required for human response will not prevent the loss. The requirement specifically does not say all failures, since this is not practical. It is intentionally left to the program to determine what failures can be isolated and recovered.

A defined methodology should be applied to each mission phase and vehicle function to determine where automation is needed, where it is cost effective. This requirement serves as the parent for the lower level requirements that must be established using this approach.

CVS0340H The CEVLS shall provide isolation and recovery from conditions which could result in loss of mission or impact mission capability.

Rationale : Recovery from failures which could result in loss of crew or vehicle is covered in a separate requirement. This requirement will serve as a parent requirement for lower level implementation of vehicle health management systems, etc. to ensure that failures which could impact mission success or capability are addressed. This requirement intentionally does not specify all conditions - which is not practical.

CVS0046H The CEVLS shall capture, archive, and make available for retrieval, mission and safety critical performance data.

Rationale : The ability to capture mission and safety critical performance data, and archive it in a retrievable format is necessary to support real-time anomaly resolution and post-mission data analysis.

3.7.1.5Interfaces

CVS0350H The CEVLS shall provide communication in accordance with the CTS IRD **(TBD-100)**.

Rationale : The complexity of possible architectures and the serial acquisition of Exploration elements dictates a standard communications interface between all elements of the Exploration System of Systems. Communications includes command, data, voice and video. Constellation must define the standard communications system in an IRD to include bandwidth, rates, security, etc. The CEV and CLV are the first CTS elements that will comply with this interface document.

TBD-100 Closure: This IRD must be developed by Constellation Systems, in coordination with the ESMD Requirements Division.

CVS0355H The CEVLS interface between the CLV and the CEV shall comply with CEVLS IRD **(TBD-87)**.

Rationale : Interface definition between the CEV and the CLV.

TBD-87 Closure: This IRD must be developed by Constellation Systems, in coordination with the ESMD Requirements Division.

CVS0360H The CEVLS interface with the Ground Support System shall comply with the CTS / Ground Support System IRD **(TBD-67)**.

Rationale : The CTS will interface with Ground Support System elements such as Mission Control and recovery/rescue forces. The CEV and CLV are the first CTS elements that will comply with this interface document.

TBD-67 Closure: This IRD must be developed by Constellation Systems, in coordination with the ESMD Requirements Division.

CVS0365H The CEVLS interface with the In-Space Support System shall comply with CTS / In-Space Support System IRD **(TBD-68)**.

Rationale : The CTS could potentially interface with In-Space Support System communication elements. If such an interface exists, it must comply with the CTS to In-Space IRD.

TBD-68 Closure: This IRD must be developed by Constellation Systems, in coordination with the ESMD Requirements Division.

3.7.2 Crew Exploration Vehicle (CEV)

3.7.2.1Mission Definition

CEV0360G The CEV shall provide the capability to conduct missions with 1, 2, 3, and 4 **(TBR-13)** crew members onboard (threshold), with an objective to include 5 and 6 crew members **(TBR-15)**.

Rationale : The requirement is intentionally written so that the CEV will be capable of operating with any number or crew, up to a full complement; this requirement could have CG, configuration, and operational implications. Note: Under 3.7.2.4.2, Crew Survival, there is a requirement (CEV0410G) that requires CTS capability to conduct a contingency mission with 0 crew.

References: ESMD-RQ-0005, “Lunar Architecture Focused Trade Study Final Results”, ESMD-RQ-0006, “Lunar Architecture Broad Trade Study Final Results”, ESMD-RQ-0015, “STTP-1 Meeting Minutes”, ESMD-RQ-0016, “STTP-2 Meeting Minutes.”

TBR-13 and TBR-15 Closures: Additional data to support this will be developed during the CE&R studies. Issue to be resolved no later than 90 days prior to the CEV SRR.

CEV0420G From the Earth Ascent Target Orbit, the CEV shall rendezvous with a target Exploration element in the Earth Reference Orbit.

Rationale : It is an essential mission capability for the CEV to operate between various Earth orbits. The staging point for Earth ascent will be optimized between the CEVLS and CEV, and may be different from the desired Earth Reference Orbit. Thus the CEV must be capable of operating from the Earth Ascent Target Orbit provided by the launch vehicle, and the necessary reference orbit where rendezvous and docking operations occur. Depending on the architecture, the CEV will be required to dock with an EDS or other mission elements in the Earth Reference Orbit.

References: ESMD-RQ-0005, “Lunar Architecture Focused Trade Study Final Results”, ESMD-RQ-0006, “Lunar Architecture Broad Trade Study Final Results”, ESMD-RQ-0015, “STTP-1 Meeting Minutes”, ESMD-RQ-0016, “STTP-2 Meeting Minutes.”

CEV0430G The CEV shall dock with a target Exploration element in the Earth Reference Orbit.

Rationale : Depending on the architecture, the CEV will be required to dock with an EDS or other mission elements in the Earth Reference Orbit. CEV provides delta velocity and other functions necessary to dock.

References: ESMD-RQ-0005, “Lunar Architecture Focused Trade Study Final Results”, ESMD-RQ-0006, “Lunar Architecture Broad Trade Study Final Results”, ESMD-RQ-0015, “STTP-1 Meeting Minutes”, ESMD-RQ-0016, “STTP-2 Meeting Minutes.”

CEV0440G When docked to a target Exploration element, the CEV shall undock and separate from the target Exploration element.

Rationale : The CEV must be able to undock and separate. This is a generic capability that applies anytime the CEV is docked with another Exploration mission element.

References: ESMD-RQ-0005, “Lunar Architecture Focused Trade Study Final Results”, ESMD-RQ-0006, “Lunar Architecture Broad Trade Study Final Results”, ESMD-RQ-0015, “STTP-1 Meeting Minutes”, ESMD-RQ-0016, “STTP-2 Meeting Minutes.”

CEV0450G From the Initial Lunar Phasing Orbit, the CEV shall provide the capability to rendezvous with a target Exploration element in the Lunar Reference Orbit **(TBR-19)**.

Rationale : Potential architectures under consideration include those that require docking of elements in lunar orbit. The Lunar Reference Orbit is established at the system level (and the defined in the glossary) for subsequent allocation to each element’s requirement set. Docking in lunar orbit enroute to the lunar surface is currently in the point of departure architecture. The delta velocity required to get the CEV from the Earth Reference Orbit into the Initial Lunar Phasing Orbit shall be provided by other elements of the CTS.

References: ESMD-RQ-0005, “Lunar Architecture Focused Trade Study Final Results”, ESMD-RQ-0006, “Lunar Architecture Broad Trade Study Final Results”, ESMD-RQ-0015, “STTP-1 Meeting Minutes”, ESMD-RQ-0016, “STTP-2 Meeting Minutes.”

TBR-19 Closure: Lunar Reference Orbit currently under review. Close no later than 90 days prior to SRR.

CEV0460G The CEV shall provide the capability to dock with a target Exploration element in the Lunar Reference Orbit **(TBR-19)**.

Rationale : Potential architectures under consideration include those that require docking of elements in lunar orbit. The Lunar Reference Orbit is established at the system level (and the defined in the glossary) for subsequent allocation to each element's requirement set. Docking in lunar orbit enroute to the lunar surface is currently in the point of departure architecture. The Lunar Reference Orbit serves as the common orbital reference for rendezvous and docking operations.

References: ESMD-RQ-0005, "Lunar Architecture Focused Trade Study Final Results", ESMD-RQ-0006, "Lunar Architecture Broad Trade Study Final Results", ESMD-RQ-0015, "STTP-1 Meeting Minutes", ESMD-RQ-0016, "STTP-2 Meeting Minutes."

TBR-19 Closure: Lunar Reference Orbit currently under review. Close no later than 90 days prior to SRR.

CEV0470G While docked to a habitable Exploration element, the CEV shall provide the capability to transfer the crew, equipment and payloads in a pressurized environment between the CEV and the habitable Exploration element.

Rationale : Crew must have sufficient insight to know that it is safe to open the hatches. Crew needs to transfer from the CEV to other elements such as a LSAM.

CEV0480B After departure of the crew for the lunar surface, the CEV shall operate with 0 crew onboard in lunar orbit for 5 days (threshold) **(TBR-30)** with an objective of 8 days (**TBR-1**).

Rationale : This requirement supports the global access missions at locations on the Moon away from the lunar base. The CTS will provide the capability for all of the mission crew to depart for the lunar surface. The CEV must remain in lunar orbit during the surface mission duration. One additional day is added to the surface mission to account for descent, ascent, and rendezvous operations.

References: ESMD-RQ-0005, "Lunar Architecture Focused Trade Study Final Results", ESMD-RQ-0006, "Lunar Architecture Broad Trade Study Final Results", ESMD-RQ-0015, "STTP-1 Meeting Minutes", ESMD-RQ-0016, "STTP-2 Meeting Minutes."

TBR-30 and TBR-1 Closures: Closure of this item will be achieved as part of further lunar lander analysis as well as the CE&R studies. Issue to be resolved no later than 90 days prior to the CEV SRR.

CEV0490G From the Lunar Reference Orbit, the CEV shall rendezvous with a target Exploration element in the Lunar Ascent Orbit.

Rationale : Providing the capability to rendezvous in lunar orbit is an essential mission capability to return the crew from the Moon. In cases where the ascent stage/vehicle performs an 'abort to lunar orbit', the CEV will be required to perform the plane change and rendezvous burns to dock with the lunar ascent stage/vehicle. Plane changes will be also required to meet the fundamental objective given the variety of landing sites under consideration.

References: ESMD-RQ-0005, "Lunar Architecture Focused Trade Study Final Results", ESMD-RQ-0006, "Lunar Architecture Broad Trade Study Final Results", ESMD-RQ-0015, "STTP-1 Meeting Minutes", ESMD-RQ-0016, "STTP-2 Meeting Minutes."

CEV0500G The CEV shall dock with a target Exploration element in the Lunar Ascent Orbit.

Rationale : Providing the capability to dock in lunar orbit is an essential mission capability to return the crew from the Moon. The Lunar Ascent Orbit is established as the common reference for the rendezvous and docking operations. The CEV must be capable of docking with the ascent stage of the LSAM.

References: ESMD-RQ-0005, "Lunar Architecture Focused Trade Study Final Results", ESMD-RQ-0006, "Lunar Architecture Broad Trade Study Final Results", ESMD-RQ-0015, "STTP-1 Meeting Minutes", ESMD-RQ-0016, "STTP-2 Meeting Minutes."

CEV0510G The CEV shall function as the active vehicle during rendezvous, docking, and undocking with other Exploration elements.

Rationale : Providing safe rendezvous, docking, and undocking operations is an essential capability for Exploration missions. Crew insight and cognition of the rendezvous, docking and undocking operations, including providing the capability to abort or provide manual override of automatic functions, enhances mission safety. Thus, when the crew is onboard, the CEV will primarily function as the active vehicle.

References: ESMD-RQ-0005, "Lunar Architecture Focused Trade Study Final Results", ESMD-RQ-0006, "Lunar Architecture Broad Trade Study Final Results", ESMD-RQ-0015, "STTP-1 Meeting Minutes", ESMD-RQ-0016, "STTP-2 Meeting Minutes."

CEV0512G The CEV shall provide the capability to function as the passive vehicle during rendezvous, docking, and undocking with other Exploration elements.

Rationale : Providing safe rendezvous, docking, and undocking operations is an essential capability for exploration missions. Crew insight and cognition of the rendezvous, docking and undocking operations, including providing the capability to abort or provide manual override of automatic functions, enhances mission safety. Thus, when the crew is not onboard, the CEV may function as the passive vehicle.

References: ESMD-RQ-0005, "Lunar Architecture Focused Trade Study Final Results", ESMD-RQ-0006, "Lunar Architecture Broad Trade Study Final Results", ESMD-RQ-0015, "STTP-1 Meeting Minutes", ESMD-RQ-0016, "STTP-2 Meeting Minutes."

CEV0520G While docked to an inhabited Exploration element, the CEV, with 0 crew onboard, shall provide the capability for the crew to ingress the CEV in a pressurized environment.

Rationale : The crew must be able to ingress an unoccupied CEV from the ascent stage of the LSAM. The crew must be able to determine environmental status of the uninhabited CEV prior to ingress.

References: ESMD-RQ-0005, "Lunar Architecture Focused Trade Study Final Results", ESMD-RQ-0006, "Lunar Architecture Broad Trade Study Final Results", ESMD-RQ-0015, "STTP-1 Meeting Minutes", ESMD-RQ-0016, "STTP-2 Meeting Minutes."

CEV0530G The CEV shall return the crew to Earth, within 5 days **(TBR-32)**, from the end of mission Lunar Ascent Orbit, independent of orbital alignment.

Rationale : Returning the crew from lunar orbit is a nominal end of mission capability. Providing the capability to return the crew from various mission destinations independent of orbital alignment is a fundamental objective for enabling safe exploration missions. Plane changes will be required to meet this fundamental objective, given the variety of lunar landing sites under consideration. The intent of this requirement is to prevent waiting in lunar orbit for planar alignment. End of mission includes the nominal planned end of mission plus any required contingency to protect for a delay in the ascent from the lunar surface.

References: ESMD-RQ-0005, “Lunar Architecture Focused Trade Study Final Results”, ESMD-RQ-0006, “Lunar Architecture Broad Trade Study Final Results”, ESMD-RQ-0015, “STTP-1 Meeting Minutes”, ESMD-RQ-0016, “STTP-2 Meeting Minutes.”

TBR-32 Closure:

CEV0030G The CEV shall accommodate 100 kg **(TBR-33)** of payload (threshold), with an objective of **(TBD-83)** kg.

Rationale : This requirement addresses the payload mass needed to accommodate exploration utilization and science requirements. This requirement will be specified in greater detail (e.g., shirtsleeve environment mass) in a future Payload ICD. The CTS requirement is to return 100 kg of payload. Since the CEV is likely the only return capability, the CEV must accommodate a minimum of 100 kg.

TBD-83 and TBR-33 Closure: Closure of this item will be achieved as part of further lunar lander analysis as well as the CE&R studies. Issue to be resolved no later than 90 days prior to the CEV SRR.

CEV0035G The CEV shall accommodate **(TBD-31)** cubic meters of payload (threshold), with an objective of **(TBD-84)** cubic meters.

Rationale : This requirement addresses the payload volume needed to accommodate maintenance, logistics, and science requirements. This requirement will be specified in greater detail (e.g., shirtsleeve environment volume) in a future Payload ICD.

TBD-31 and TBD-84 Closures:

3.7.2.2Mission Success

CEV0040H The CEV shall provide single failure tolerance to loss of mission and critical hazards, except where the CEV meets NASA approved "Design for Minimum Risk" Criteria.

Rationale : This requirement establishes the failure tolerance design criteria for the system against the loss of successful mission completion, non-life-threatening injuries, or significant damage to the system. NPR 8705.2 has failure tolerance criteria to prevent loss of life, however it does not provide measures to preclude loss of other mission assets. Although aborts and crew escape systems help to ensure survival of the crew and other personnel, loss of high value hardware and the additional risk of relaunching the crew could jeopardize completion of a mission. This requirement ensures robustness is built into the system through tolerance to failures. The ESS Programmatic Requirements detail the "Design for Minimum Risk" criteria (ESMD-RQ-0010).

3.7.2.3Performance Characteristics

CEV0540G The CEV shall provide remotely commanded rendezvous capability, with objectives of autonomous and automated rendezvous capability.

Rationale : Required for lunar orbit docking after completion of lunar surface operation, in preparation for return to Earth. Automated rendezvous is required by other CTS elements, therefore the system and technologies will be available. The CEV will need to be remotely controlled to achieve the proper orbital plane for rendezvous with the LSAM, and then be commanded to a mode ready for rendezvous as a passive target. The CEV is also required to be capable of being remotely controlled to rendezvous with the LSAM as the active element, to provide functional redundancy. As an objective, the CEV should also have the capability to automatically and autonomously rendezvous with the LSAM after being commanded to perform an LSAM rendezvous.

CEV0550G The CEV shall provide automated docking capability.

Rationale : This capability is necessary for lunar orbit docking on return to Earth, when the CEV has no crew and remote commanding of the CEV docking is not adequate as the only means of performing this critical event. This capability will be required by other CTS mission elements, therefore the system and technologies will be available.

CEV0555G The CEV shall provide automated undocking and separation capability.

Rationale : Required for lunar orbit undocking so that the LSAM can descend to the lunar surface. This capability is required by other CTS mission elements, therefore the system and technologies will be available.

CEV0560G The CEV shall provide automated control during Earth entry (both nominal and abort).

Rationale : Automated control is required during the dynamic entry phase of flight.

CEV0570G The CEV shall provide autonomous operations for aborts from LEO (threshold) with an objective of autonomous operations throughout the mission.

Rationale : Crew safety requires the ability to return from LEO without help from the ground. Provides requirement for objective of full autonomy, which is desirable when it is cost effective.

CEV0400H The CEV shall provide manual intervention of automated functions critical to mission success and crew safety.

Rationale : Manual intervention of automated control can be executed by ground control or flight crew. Human intervention capability is required to ensure that automated functions do not perform actions that are inappropriate in a particular failure scenario. For example, previous system or sensor failures have made an automated response undesirable. This requirement specifically does not say "all automated functions" - that determination is left to the program.The requirement for manual intervention of functions critical to crew survival is covered in NPR 8705.2.

3.7.2.3.1 Operations

CEV0085H The CEV shall provide 48 hours **(TBR-60)** of mission consumables to accommodate unplanned or contingency events, with an objective of 72 hours **(TBR-61)**.

Rationale : The purpose of this requirement is to ensure that the CEV has the capability to accommodate delays during the mission to solve problems.
This requirement is exclusive of launch scrub turnaround requirements. In the event of a launch scrub, the CEV will require consumables replenishment to maintain the margins specified in this requirement. This requirement is also exclusive of requirements to support CEV loiter time in LEO to protect for launch delays (for example, if the CEV launches two days before the optimum launch time to account for potential CEV launch delays, then the consumables required to support the loiter time will not count towards the contingency consumables specified in this requirement).

48 hours is the standard used today in shuttle operations, but is driven primarily by landing constraints. For lunar exploration missions, the CEV will need to protect for a delay in the crew leaving the surface of the moon and potentially a delay in leaving lunar orbit to return to Earth. 24 hours for each situation provides adequate margin. In LEO D&T missions, since the CEV is returning from Earth orbit to a designated landing site, the 48 hour delay will accommodate potential weather delays at the landing site.

TBR-60 and TBR-61 Closures: Closure of this item will be achieved no later than 90 days prior to the CEV SRR.

3.7.2.3.2 Flight Control

CEV0250G The CEV shall control mated operations while docked to other Exploration elements.

Rationale : The CEV will be docked to various elements during the mission, and only one element at a time can control the GN&C function. Because the CEV will be docked to multiple elements (EDS, LSAM), and the CEV needs the Guidance, Navigation, and Control (GN&C) capability to perform anytime return, it is preferable for the CEV to provide the GN&C capability (either as primary or backup). This capability could be implemented by the CEV commanding the subsystems on both elements. “While docked to other Exploration elements” excludes the CEV to CEVLV interface.

CEV0252G The CEV shall provide the capability to be controlled during mated operations while docked to other Exploration elements.

Rationale : The CEV will be docked to various elements during the mission, and only one element at a time can control the GN&C function. During periods when the CEV is the un-crewed element (e.g., immediately prior to crew departure to the lunar surface in the LSAM), it may be preferable to the crewed element to control mated operations.

3.7.2.3.3 Communications

CEV0110H The CEV shall simultaneously communicate with a threshold of two **(TBR-77)** Exploration elements, objective **(TBD-68).**

Rationale : The CTS will require simultaneous communication with Mission Control (Ground Support System) and other Exploration elements such as launch control, EDS (Spirals 2 and 3), Destination Surface System mission elements (in Spiral 3), recovery forces, etc. This is a basic requirement driven by the complexity of the ESS. For example, a CEV performing proximity operations with an LSAM will require communications with Mission Control and the LSAM simultaneously. Communication includes voice, data, command, and video as specified in the IRD.

TBD-68 and TBR-77 Closures: Closure of this item will be achieved no later than 90 days prior to the CEV SRR.

CEV0580G The CEV shall communicate with target Exploration elements during proximity operations in accordance with CTS IRD **(TBD-100)**.

Rationale : The CEV will need to ensure target element is configured for docking, and that the target vehicle attitude control system is properly configured after docking. Also, after undocking, the CEV will need to tell the target element when it is cleared to begin the next mission phase (i.e., disposal, transit to refuel, etc.). Communication includes voice, data, command, and video as specified in the IRD.

TBD-100 Closure: This IRD must be developed by Constellation Systems, in coordination with the ESMD Requirements Division.

CEV0590G While operating in lunar orbit, the CEV shall provide communication with other Exploration elements on the lunar surface in accordance with the CTS IRD **(TBD-100)**.

Rationale : The CEV must provide data to the crew on the surface during the surface mission. The surface crew needs to have situational awareness of the CEV status and location in case early termination of lunar surface operations and return to the CEV are required. The crew may also need to initiate a CEV orbital maneuver in order to perform ascent and rendezvous. Communication includes voice, data, command, and video as specified in the IRD.

TBD-100 Closure: This IRD must be developed by Constellation Systems, in coordination with the ESMD Requirements Division.

CEV0600G While operating in lunar orbit, the CEV shall provide communication with other Exploration elements in transit to and from the lunar surface in accordance with the CTS IRD **(TBD-100)**.

Rationale : The CEV must provide data to the crew during the descent to the surface and during the ascent from the lunar surface. The crew needs to have situational awareness of the CEV status and location to perform ascent operations, or to abort descent operations and return to the CEV. The crew may also need to command a CEV orbital maneuver in order to complete a rendezvous and docking. Communication includes voice, data, command, and video as specified in the IRD.

TBD-100 Closure: This IRD must be developed by Constellation Systems, in coordination with the ESMD Requirements Division.

3.7.2.3.4 Crew Environment

CEV0610G The CEV shall provide crew habitation from crew ingress until crew egress or until transfer of the habitation function to another element.

Rationale : The CEV must provide habitation from crew ingress until egress on the surface of the Earth or until another CTS element provides habitation functions. Habitation includes volume, ECLSS, food, water, waste management, etc. If the CEV is mated to another CTS element that provides habitation, sharing of habitation functions is not precluded by this requirement. It is expected that, at a minimum, volume will be shared between the two habitable elements.

CEV0612H The CEV net habitable volume shall comply with the requirements in NASA Standard 3000 **(TBD-2).**

Rationale : NASA 3000 sets the minimum habitable volume requirements based on mission duration

TBD-2 Closure: Updates to NASA Standard 3000 are required prior to CEV RFP release. If not updated, then this requirement will be deleted.

CEV0140H The CEV shall provide the net habitable volume for simultaneous crew activities necessary for the mission phase.

Rationale : The necessary habitable volume is dependent on required crew activities. Simultaneous crew operations are required so that a critical activity is not interrupted by the need to perform another time critical activity. Examples of crew activities include trajectory monitoring and control, systems management, suit doffing and donning, waste management, etc. The volume required for a short duration mission in LEO is different than the volume required for a mission to lunar orbit. Depending on the architecture, the CEV may not provide the habitable volume for the transit to and from the moon - therefore, this requirement is written to allow a minimum volume CEV architecture.

CEV0630G When mated to another habitable exploration element, the CEV habitable volume shall be accessible to the onboard crew.

Rationale : Even when the CEV is docked to another habitable element, the volume of the CEV must be accessible to the crew.

CEV0150H The CEV habitable environment shall be maintained in accordance with the CTS IRD **(TBD-100)**.

Rationale : A habitable environment IRD is required to document the habitable environments interface between joined habitable element volumes. The IRD must set a common standard for mated O2 concentration, total system pressures, temperature and humidity. These values will affect parts and material selection in each element.

TBD-100 Closure: This IRD must be developed by Constellation Systems, in coordination with the ESMD Requirements Division.

CEV0130H The CEV shall limit accelerations and rotational rates on the crew in accordance with NASA Standard 3000, Volume I, Section 5.3 **(TBR-72)**.

Rationale : To safely transport the crew, both the axial and rotational acceleration rates imparted to the crew must be limited to acceptable levels. The acceptable acceleration rates are documented in NASA STD 3000.

TBR-72 Closure: NASA STD 3000 does not currently account for acceleration rates that may be required to preserve crew life in the event of an abort of an abort or escape, and it is out of date for nominal forces. Updates to NASA STD 3000 are required prior to CEV RFP release.

CEV0620G The CEV transfer volume shall comply with NASA STD 3000, Volume I, Section 8.0 **(TBR-75)**.

Rationale : A common standard for all habitable elements must specified. This standard will set hatch size, tunnel width, etc.

TBR-75 Closure: NASA STD 3000 is currently undergoing an update. The current transfer design guidelines and requirements should be reviewed and updated as appropriate to support the CEV RFP release. Issue to be resolved prior to RFP release.

3.7.2.3.5 Software

CEV0170H The CEV shall comply with NPR 7150, NASA Software Engineering Requirements.

Rationale : NPRs are agency level requirements and not at the discretion of the Directorate.

3.7.2.4Safety

3.7.2.4.1 General

CEV0180H The CEV shall comply with NPR 8705.2, Human Rating Requirements and Guidelines for Space Flight Systems.

Rationale : NPRs are Agency level requirements and not at the discretion of the Directorate.
In order to fly humans in space, each element of the System of Systems that interfaces with the crew is required to be certified as human rated. NPR 8705.2 delineates the requirements and process for obtaining that certification and is applicable to those elements that interact with the crew.
The current version is NPR 8705.2, with Change 2 dated June 25, 2004. The document is currently under review, and a new, approved version is expected prior to release of the CEV RFP.

CEV0190H The CEV shall comply with NPR 8715.3, NASA Safety Manual.

Rationale : NPRs are Agency level requirements and not at the discretion of the Directorate. This document contains the requirements and procedures that define the NASA Safety Program for minimizing the risk to personnel and equipment.

CEV0200H The CEV shall comply with NASA-STD-8719.13, Software Safety Standard, for all Safety-Critical Software.

Rationale : Software is a critical component of all complex space systems. Safety Critical Software (as defined in NASA-STD-8719.13) must be developed and tested to ensure the safety of the crew. Although 8719.13 is a standards document, it contains specific software requirements.

CEV0210H The CEV, when launching from a U.S. range, shall comply with NPR 8715.x, NASA Range Safety Program **(TBD-65)**.

Rationale : NPRs are Agency level requirements and not at the discretion of the Directorate. Space systems launched from US ranges are required to comply with Air Force Range Requirements as tailored for the system. The Range Safety NPR will contain the NASA tailored requirements to launch on US Ranges.

TBD-65 Closure: The NPR is currently in NODIS review cycle, with OSMA responsibility. Completion is expected in early 2005.

3.7.2.4.2 Crew Survival

CEV0220H The CEV shall provide dual failure tolerance to catastrophic hazards, including permanent disability or loss of life, except where the CEV meets NASA approved "Design for Minimum Risk" criteria.

Rationale : This requirement establishes the failure tolerance design criteria for the system against all types of catastrophic hazards. NPR 8705.2 has failure tolerance criteria to prevent loss of life and permanent disability, however it does not provide measures to preclude other type of catastrophic hazards, such as non-debilitating injury, loss of major vehicle segments or major facilities. Failure to mitigate against these hazards puts the crew and personnel at risk, as well loss of high value strategic assets. The programmatic requirements detail the "Design for Minimum Risk" criteria.

CEV0260H The CEV shall provide abort capability to return to Earth at any time from LEO's up to the Earth Reference Orbit.

Rationale : CEV provides capability to abort the mission and return to Earth at any point during Earth orbit operations.

CEV0312G The CEV shall provide abort capability to return the crew to Earth during transit from Earth orbit to lunar orbit.

Rationale : CEV provides capability to abort the mission and return to Earth at any point along the mission profile during transfer from Earth orbit to lunar orbit.

CEV0315G The CEV shall provide abort capability to return the crew to Earth from lunar orbit, within 5 days **(TBR-32)**, at any time during the mission duration, independent of orbital alignment.

Rationale : CEV provides the capability to leave lunar orbit either prior to descent by the crew to the lunar surface, or if the surface mission is terminated earlier than planned, and the crew returns to the CEV. "Independent of orbital alignment" means that the CEV must be able to accommodate the Wedge Angle for return. For the long duration missions to the polar region, the required mission duration of 42 days (threshold) drives the CEV to accommodate the worst case plane change. For the global access missions to mid-latitudes, the worst case plane change is bounded by the mission duration of 4 days (threshold) and the optimum CEV orbit established for that mission duration.

References: ESMD-RQ-0005, "Lunar Architecture Focused Trade Study Final Results", ESMD-RQ-0015, "STTP-1 Meeting Minutes".

CEV0330G Returning from beyond Earth orbit, the CEV shall provide direct return capability to the Earth surface.

Rationale : Direct return required for aborts/safety. Aerocapture and phasing left as option to CEV Program.

CEV0280H The CEV shall provide for 36 hours **(TBR-35)** of crew survival after landing.

Rationale : The CEV must provide for survival capability while awaiting rescue. The requirement to rescue the crew following an abort will be part of the Ground Support System requirements. It is possible that for some aborts into the Atlantic Ocean, the first arrival of rescue forces would provide additional survival equipment until recovery forces arrive.

TBR-35 Closure: This issue will be closed no later than 90 days prior to CEV System Requirements Review.

CEV0410G The CEV shall provide the capability to conduct a mission from Earth through docking operations in lunar orbit, with 0 crew onboard, and return back to Earth with crew. **(TBD-16)**

Rationale : Provides functionality for a potential crew rescue mission scenario. Drives level of automation in subsystems. The requirement uses the term “conduct a mission” to acknowledge that it will likely be necessary for the CEV to function with other elements of the exploration system to transit to lunar orbit to Earth.

TBD-16 Closure: This issue will be closed no later than 90 days prior to the CEV SRR.

CEV0320H The CEV shall provide for contingency EVA. **(TBD-86)**

Rationale : Contingency EVA was identified by the OAG as a required capability.

TBD-86 Closure: TBD applies to the entire requirement. Specific contingency tasks have not been identified for the CEV. Therefore, this requirement will remain TBD, pending further study.

3.7.2.4.3 Vehicle Health

CEV0230H The CEV shall detect and annunciate conditions that could result in loss of human life, loss of vehicle, loss of mission, or significantly impact mission capability.

Rationale : This requirement captures functionality, such as Integrated Health Management, for the detection of system failures. For situational awareness, the crew and ground control must be aware of significant changes in vehicle status, even if automated systems respond to the condition. This requirement intentionally does not specify all failures - which is not practical. Also, it is left to the program to interpret "significantly impact mission capability" in the lower level requirements. This requirement serves as a parent to flight element health status monitoring requirements.

CEV0240H The CEV shall provide autonomous isolation and recovery, with an objective of automated isolation and recovery, from conditions which could result in loss of human life or loss of vehicle.

Rationale : This requirement captures functionality, such as Integrated Health Management and redundancy management, for the detection and mitigation of system failures. Reliance on communication with mission control to avoid loss of vehicle or loss of life is not acceptable. Automated recovery should be used when practical, and for all cases where the time required for human response will not prevent the loss. The requirement specifically does not say all failures - since this is not practical. It is intentionally left to the program to determine what failures are can be isolated and recovered.

A defined methodology should be applied to each mission phase and vehicle function to determine how much automation is needed, and where automation is cost effective. This requirement serves as the parent for lower level requirements that must be established using this approach.

CEV0290H The CEV shall provide isolation and recovery from conditions which could result in loss of mission or significantly impact mission capability.

Rationale : Recovery for failures which could result in loss of crew or vehicle is covered in a separate requirement. This requirement will serve as a parent requirement for lower level implementation of vehicle health management systems, etc. to ensure that failures which could impact mission success or capability are addressed. This requirement intentionally does not specify all conditions - which is not practical.

CEV0047H The CEV shall capture, archive, and make available for retrieval, mission and safety critical performance data.

Rationale : The ability to capture mission and safety critical performance data, and archive it in a retrievable format is necessary to support real-time anomaly resolution and post-mission data analysis.

3.7.2.5Interfaces

CEV0300H The CEV shall communicate in accordance with the CTS IRD **(TBD-100)**.

Rationale : The complexity of possible architectures and the serial acquisition of Exploration elements dictates a standard communications interface between all elements of the Exploration System of Systems. Communications includes command, data, voice and video. Constellation Systems must define the standard communications system in an IRD to include bandwidth, rates, security, etc. The CEV and CEVLS are the first CTS elements that will comply with this interface document.

TBD-100 Closure: This IRD must be developed by Constellation Systems, in coordination with the ESMD Requirements Division.

CEV0310H The CEV interface with Ground System shall comply with the CTS/ Ground Support System IRD **(TBD-67)**.

Rationale : The CEV will interface with Ground Support Systems such as Mission Control and recovery / rescue forces. The CEV and CEVLS are the first CTS elements that will comply with this CTS interface document.

TBD-67 Closure: This IRD must be developed by Constellation Systems, in coordination with the ESMD Requirements Division.

CEV0335H Upon return to Earth, the CEV shall provide the interfaces required for recovery of the crew and CEV, in accordance with the CTS / Ground Support System IRD **(TBD-67)**.

Rationale : The CEV must provide interfaces necessary to allow recovery forces to ingress the vehicle, lift the CEV, etc.

TBD-67 Closure: This IRD must be developed by Constellation Systems, in coordination with the ESMD Requirements Division.

CEV0080G The CEV shall dock and undock with other habitable Exploration elements in space utilizing a single common docking mechanism and interface in accordance with the CTS IRD **(TBD-100)**.

Rationale : The acquisition strategy, which develops the CEV within a potential family of architectures, dictates the use of a common docking system for all in space mating operations. This will allow the CEV to dock to different elements at different times in the mission profile using the same docking system. Development of this docking system must be a high priority for Constellation Systems and must be done concurrent with CEV development.

TBD-100 Closure: This IRD must be developed by Constellation Systems, in coordination with the ESMD Requirements Division.

CEV0090G The CEV shall rendezvous, dock and undock with other Exploration elements in space utilizing a rendezvous and proximity operations sensor capability in accordance with the CTS IRD **(TBD-100)**.

Rationale : The acquisition strategy, which develops the CEV within a potential family of architectures, dictates the use of a common sensor package for all in space mating operations. Since different elements may be mated at different times during the mission profile, the sensors and targets on each element must be compatible. Development of the sensor package must be a high priority for Constellation Systems.

TBD-100 Closure: This IRD must be developed by Constellation Systems, in coordination with the ESMD Requirements Division.

CEV0100G When docked to another Exploration element(s), the CEV shall communicate with the other element(s) in accordance with the CTS IRD **(TBD-100)**.

Rationale : The NASA human rating requirements dictate extensive crew insight into critical mission events which will be performed by other Exploration mission elements while docked to the CEV. It is expected that these communications will include data, command, video, voice, fault detection and annunciation. The complexity of possible architectures dictates a standard hardline communications interface between all docked elements of the ESS. The CEV and the EDS are potentially the first CTS elements affected by this IRD.

TBD-100 Closure: This IRD must be developed by Constellation Systems, in coordination with the ESMD Requirements Division.

CEV0095H The CEV interface with the In-Space Support System shall comply with the CTS / In-Space Support System IRD **(TBD 68).**

Rationale : The CEV will need to interface with in-space communication and navigation systems. This interface is specified in the applicable IRD.

TBD-68 Closure: This IRD must be developed by Constellation Systems, in coordination with the ESMD Requirements Division.

4 Verification (Reserved)

5 Glossary and Acronym List

5.1 Glossary

Abort Early mission termination due to failure(s) that preclude mission continuation. Return to Earth of the crew is accomplished inside the spacecraft designed for Earth return and landing (see Abort to Earth, Abort to Orbit).

Abort to Earth Early mission termination, with direct return to the Earth's surface as the immediate objective.

Abort to Orbit An early mission termination that has an immediate objective of placing a crewed flight system in Earth (or destination vicinity) orbit, prior to return to the Earth's surface.

Annunciate To provide a visual, tactile or audible indication.

Ascent The function of liftoff from the Earth (or mission destination) surface, to spacecraft insertion into Earth/destination orbit.

Automated control Automatic, as opposed to human operation or control of a process, equipment or a system; or the techniques and equipment used to achieve this. Automation is the control or execution of actions with no human interaction. Automated control does not exclude the capability for manual intervention / commanding, but manual intervention / commanding is explicitly not required to accomplish the function.

Autonomous operations Defined as a flight vehicle operating independent of external commands or control (i.e., commands from mission control on Earth). Autonomous operations can be fully automated or require some degree of manual commanding/intervention by the onboard crew. Autonomous operations that do not require onboard crew involvement are, by definition, automated; therefore, the term "autonomous operations" used in the requirements assumes onboard crew involvement in the operations.

Berthing A method of mating two or more Exploration elements in space. During a berthing operation, the two elements are mechanically connected prior to the structural capture and final mating (i.e., one element grapples the other with a robotic arm). One element controls the trajectory and attitude of the other element for the contact and capture. Final mating is generally performed by the berthing mechanism (also see docking).

Cargo Delivery System (CDS) The CDS encompasses the capability to deliver all non-CEV flight elements needed to accomplish human exploration objectives. At such time as CDS elements dock with the CEV, they are part of a human crew occupied system, and are considered part of the CTS.

Cargo Launch Vehicle The Cargo Launch Vehicle is an element of the Cargo Delivery System. The Cargo Launch Vehicle will perform the ascent function for non-crewed elements of the CTS (EDS, LSAM), into an Earth Orbit. Since the Cargo Launch Vehicle will not carry human crew, it will not require Human-Rating.

Catastrophic Hazard A condition that may cause death or permanently disabling injury, major system or facility destruction on the ground, or major systems or vehicle destruction during the mission. (From NPR 8715.3 Safety Manual)

Consumables Resources that are consumed in the course of conducting a given mission. Includes propellant, power, habitability items (e.g., gaseous oxygen), and crew supplies.

Contingency EVA Capability An EVA capability provided to deal with critical failures or circumstances, which are not adequately protected by redundancy or other means.

Crew Exploration Vehicle (CEV) The CEV provides crew habitation and Earth reentry capability for all Exploration Spirals.

Crew Exploration Vehicle Launch Segment (CEVLS) The CEVLS consists of a Crew Exploration Vehicle (CEV), a Crew Launch Vehicle (CLV), and all the dedicated ground support infrastructure necessary to launch the CEV to Earth orbit.

Crew Launch Vehicle (CLV) The CLV is an element of the CTS. The CLV will be human-rated, and will deliver the CEV into a mission-specific Earth Ascent Target Orbit.

Crew Member Human onboard the spacecraft or space system during a mission.

Crew Transportation System (CTS) The CTS encompasses the flight elements needed to deliver a human crew from Earth to a mission destination, and return the crew safely to Earth. The CTS must interact with the Ground Support System (GSS) during all Spirals; current architectures require delivery of the EDS and LSAM to Earth orbit through use of the CDS.

Critical Hazard A condition that may cause a severe injury or occupational illness, loss of mission, or major property damage to facilities, systems, or flight hardware.

Day Defined as an Earth day of 24 hours.

Destination Surface System (DSS) The DSS encompasses all elements (exclusive of the surface lander that transports the crew to the destination surface) necessary to enable a long-duration human exploration mission. Examples of DSS elements include a long-duration habitation module, surface power capability, and surface transportation systems. DSS elements will be delivered to the destination surface via the CDS. It is likely that these assets will be pre-deployed in advance of the crew that will utilize them to execute a given Exploration mission.

Destination Surface to Destination Vicinity Phase Starts with the initiation of the ascent (T0) from the destination surface. Representative mission activities include: ascent, abort, and orbit insertion or libration capture. Phase ends after successful destination vicinity insertion/capture.

Destination Vicinity Operations Phase (A) Starts at the successful insertion/capture at the destination vicinity. Representative mission activities include: loiter and phasing, vehicle and system checkout, crew-cargo transfers, undocking and separation. Phase ends at the successful separation of surface lander system for descent burn.

Destination Vicinity Operations Phase (B) Starts after the successful destination orbit insertion or libration point capture, following ascent from destination surface. Representative mission activities include: phasing, vehicle-system checkout, crew-cargo transfer, undocking and separation maneuver, element disposal and/or safing. Phase ends at the completion of the Trans-Earth Injection burn.

Destination Vicinity to Earth Phase Begins with completion of Trans-Earth Injection burn and includes mid-course corrections, cruise to Earth vicinity, element separation and element disposal. Ends with arrival at Earth entry interface or insertion to Earth orbit.

Destination Vicinity to Destination Surface Phase Starts at the initiation of the descent burn from destination vicinity (destination deorbit burn or libration departure burn to destination). Representative mission activities include: descent to destination surface, descent aborts, landing, propulsion system shutdown and safing. For libration architectures, additional activities include orbit capture, phasing, and de-orbit maneuvers. Phase ends when the vehicle has completed all landing activities on the destination surface, including propulsion system shutdown and safing.

Docking A method of mating two or more Exploration elements in space. In a docking operation, the structural mechanisms are brought into contact and captured through independent control of the two vehicles' flight path and attitude. Final mating is generally accomplished by the docking mechanism (also see Berthing).

Earth Ascent Target Orbit The planned orbit, at conclusion of the ascent function.

Earth Departure Stage (EDS) EDS will be used to provide the propulsive force needed to transfer the various flight elements to destination phasing orbits (including the CEV and LSAM).

Earth-Moon Transit Transit of a spacecraft between Earth vicinity and Lunar vicinity in either direction.

Earth Orbit Operations Phase (A) Starts with completion of Earth orbit insertion. Representative activities include: phasing, rendezvous, docking and loiter. Ends with completion of a burn to leave Earth orbit (i.e., Trans-Lunar Injection burn or de-orbit burn).

Earth Orbit to Destination Vicinity Phase Starts after completion of vehicle injection burn (i.e., Trans-Lunar Injection) and includes mid-course corrections, element separation/disposal, and cruise to destination vicinity. Ends with successful insertion/capture at destination vicinity.

Earth to Orbit Phase Starts with liftoff. Representative activities include liftoff through ascent to orbit, ascent crew escape/abort and re-entry/descent during aborts, disposal of elements. Ends with insertion to a stable, 24 hour Earth orbit or return to Earth (in the event of an abort).

Earth Re-entry Phase Begins with arrival at Earth entry interface (for direct re-entry) or completion of Earth orbit injection (for aerocapture), continues through the de-orbit burn and ends with landing on the Earth's surface. Encompasses activities necessary to successfully execute direct-to-Earth aborts during ascent and direct entry return from beyond Earth orbit.

Earth Reference Orbit The orbit designated for assembly of Exploration System elements prior to departure for exploration destinations, defined by the following parameters: Inclination: 28.5-29.0 degrees; Launch Azimuth: 90+/- 5 degrees; Altitude: 307 km - 407 km.

Entry footprint Region on Earth’s surface defined by the boundaries of the Earth entry corridor for a given vehicle.

Equatorial Region of the Moon Defined as the area between 0-20 degrees lunar latitude (threshold), with an objective of 0-30 degrees **(TBR)**.

Escape Early mission termination that requires emergency egress of the Crew from the failing spacecraft, possibly using an escape system (e.g., extraction, ejection, escape pod).

Exploration Spiral 1 (Crew Exploration Development and Test) Encompasses the capabilities necessary to insert humans into Earth orbit and return them safely to Earth, employing a post-Space Shuttle flight system. The flight elements of the Exploration Spiral 1 Crew Transportation System are the Crew Exploration Vehicle and CEV Launch Vehicle. Robotic Precursor Missions that are scheduled to launch prior to the Earth orbit demonstration of the Spiral 1 CTS are considered Exploration Spiral 1 missions.

Exploration Spiral 2 (Lunar Global Access for Human Exploration) Encompasses the capabilities necessary to execute human lunar exploration anywhere on the surface of the moon. Lunar global access exploration missions will be 4-7 days in duration on the lunar surface, and do not require pre-deployed surface systems (e.g., Habitation Module or Surface Power). Robotic Precursor Missions scheduled to launch after the Spiral 1 CTS flight demonstration, and prior to the first Spiral 3 Lunar mission are considered Exploration Spiral 2 missions.

Exploration Spiral 3 (Lunar Base and Mars Testbed) Encompasses the capabilities necessary to execute a long-duration human lunar exploration campaign. This campaign requires development of extensive surface systems (e.g., habitation and surface power system). Robotic Precursor Missions that are scheduled to launch after the last Spiral 2 extended- duration lunar mission, and prior to the initial Exploration Spiral 4 mission are considered Exploration Spiral 3 missions.

Exploration Spiral 4 (Crew Transportation System Mars Flyby) Encompasses the capabilities to conduct a Mars flyby mission using elements of the Human-Mars Crew Transportation System. Upon completion of successful Mars flyby(s), Exploration Spiral 5 will commence. Robotic Precursor Missions scheduled to launch after the first CTS Mars Flyby mission, and prior to the first Human-Martian surface mission are considered Spiral 4 missions.

Exploration Spiral 5 (Human Mars Surface Campaign) Spiral 5 encompasses the capabilities necessary to execute human Mars exploration missions. Robotic Precursor Missions scheduled to launch after the final Mars flyby mission, and prior to the start of Exploration Spiral 6 (content currently undefined) are considered Spiral 5 missions.

Ground Operations Phase Begins with the start of mission planning. Representative activities include: mission planning, training, receipt of government hardware/software, acceptance, test, checkout, repair, inspection, assembly, integration, servicing and countdown activities. Also includes ground contingency, emergency, abort and turnaround operations. Phase ends with vehicle liftoff.

Ground Support System This system provides all common ground-based capabilities (e.g., mission control, launch-site processing) needed to execute Exploration missions. Facilities and capabilities that are unique to a single Exploration System, such as the CTS, will be included as part of the system it supports.

Guidance and Control The process of directing the movements of a space vehicle, including selection of a flight path and making changes in attitude and speed.

Inclination The angle between the plane of an orbit and the Earth's equator for all geocentric orbits.

In-Space Support System (IS^3) This system will encompass capabilities provided by infrastructure elements (e.g., a communication satellite or network) that are placed in orbital, or lunar/planetary locations. These capabilities are exclusive of those provided by elements of the DSS.

Independent Technical Authority (ITA) A responsiblity owned by the NASA Chief Engineer, which is then delegated through the issuance of warrants. A warrant holder is designated as compliance officer over an identified set of engineering and technical requirements or standards.

Integrated Logistics Support (ILS) Is an approach that enables disciplined, unified and iterative management of support considerations into system and equipment design. ILS includes development of support requirements that are related to readiness objectives, to design, and to each other. Requirements in turn drive acquisition of required support; ILS is then employed during the operational phase.

Initial Lunar Phasing Orbit Used in Spiral 2 and 3 to define the orbit where the CEV will assume delta V requirements for a potential docking in lunar orbit. Defined by the following parameters: Altitude: 100 km x 500 km +/- **(TBD-6)** km **(TBR-34)**; Maximum inclination error with respect to the Lunar Reference Orbit; 0.5 degrees **(TBR-28)**.

Launch Availability The likelihood that a given launch will be achieved without a scrub once the mission timeline (first element launch for a multiple launch mission) or the launch countdown call to stations (for a mission scenario involving a single launch) has commenced. Launch availability is composed of four elements: system availability, launch probability, launch site weather constraints and abort weather constraints. Launch Availability can be expressed as: P(LA) = P(SA) x P(LP) x P(LW) x P(AW)

Where:
P(LA) = Launch Availability (overall probability of achieving a launch)
P(SA) = System Availability (probability of hardware being acceptable for launch)
P(LP) = Launch Probability (probability that the vehicle limits are not violated by upper level winds or other natural environment phenomena)
P(LW) = Launch Weather (probability that other launch site weather constraints are not violated)
P(AW) = Abort Weather (probability that abort weather constraints are not violated)

Launch Azimuth The initial heading of a powered vehicle at launch.

Launch Opportunity The period of time during which the relative position of the launch site and orbital plane permit a launch vehicle to perform the ascent function.

Long-Duration (Lunar Mission) Human missions to the lunar surface that require pre-deployed Surface Systems. This capability is a requirement in Exploration Spiral 3, and encompasses surface stays from 42 days (threshold) up to 98 days (objective) **(TBR-70)**.

Low Earth Orbit (LEO) A stable orbit around the Earth with a minimum orbital altitude of 170 km.

Lunar Architecture Focused Trade Study Ongoing engineering analysis (led by NASA JSC) of lunar architecture and mission design options, in support of Exploration architecture decision-making. Results of this study are captured in document ESMD-RQ-0005, "Lunar Architecture Focused Trade Study Final Results".

Lunar Ascent Orbit Used in Exploration Spirals 2 and 3 to define the orbit that the LSAM must achieve when launching from the lunar surface. Defined by the following parameters: Altitude: 100 km +/- **(TBD-8)** km; Inclination angle (wedge angle) with respect to Lunar Reference Orbit: Maximum of 10 degrees **(TBR-71)**.

Lunar Reference Orbit Used in Exploration Spirals 2 and 3 to define the lunar orbit for rendezvous and docking of Exploration elements. Defined by the following parameters: Altitude: 100 km +/**- (TBD-8)** km; Inclination: Optimized for the mission.

Lunar Surface Access Module (LSAM) Provides crew transport to the lunar surface from the Lunar Reference Orbit and return from the surface to the Lunar Ascent Orbit.

Mating The act of mechanically connecting together two major elements of a system. Mating can be performed in space, through docking or berthing, or on the ground through docking, berthing, or other interfaces.

Mission Capable Refers to the status of an Exploration flight element or mated elements, which have sufficient consumables to fully execute its intended mission from its current location in space.

Mission Opportunity Refers to the Earth departure window to conduct a mission to another planetary destination such as the Moon or Mars. Typically constrained by orbital mechanics and the design of the Exploration System. If assembly of elements in Earth orbit is required, then "Mission Opportunity" refers to the departure window from Earth orbit based on the capability of the Exploration System.

Mission Phase Definitions Used as the basis for functional flow and decomposition of reference Spiral 3 human exploration mission. The Mission Phases identified were Ground Operations, Earth to Orbit, Earth Orbit Operations, Earth Orbit to Destination Vicinity, Destination Vicinity Operations (A), Destination Vicinity to Surface, Surface Operations, Destination Surface to Destination Vicinity, Destination Vicinity Operations (B), Destination Vicinity to Earth, Earth Reentry, and Recovery (see associated definitions).

Net Habitable Volume The functional pressurized volume left available to the crew after accounting for the loss of volume due to deployed equipment, stowage, trash, and any other items which decrease functional volume. The gravity environment corresponding to the habitable volume must be specified.

Objective Used in requirements language to define the desired capability above the threshold that should be evaluated for feasibility and affordability. Capabilities above the objective are not expected to be pursued or analyzed.

Payload The onboard scientific and exploration utilization (i.e. ISRU) equipment carried by a given spacecraft, generally quantified in terms of mass and volume. Also expressed as the entire mass delivered by a launch vehicle, to orbit.

Polar Regions of the Moon Defined as the area between 80-90 degrees **(TBR-74)** lunar latitude (threshold), with an objective of 70-90 degrees **(TBR-76)**.

Probabilistic Risk Assessment A set of methodologies employed to determine quantitative probability a given end state or states (e.g., Loss of Mission, Loss of Crew) will occur. Probabilistic Risk Assessment results can be used to develop or validate Fault Trees and Failure Modes analysis. They also can be used as a tool for making design and logistics decisions.

Proximity Operations Orbital flight operations conducted during any period when two or more vehicles are operating near enough to affect one another (e.g., prior to or post rendezvous and docking).

Recovery Phase Begins with completion of Earth surface landing and includes recovery forces operations, vehicle safing, vehicle configuration for recovery, crew egress, crew return to post-mission facilities. Ends with vehicle recovery to post-mission facilities for refurbishment or disposal.

Remotely Commanded Operations The capability to operate a vehicle, system, or subsystem from an external location (e.g., mission control). Remotely commanded operations do not require the presence of an onboard crew.

Robotic Precursor Mission A robotic spacecraft mission that supports The Vision by achieving scientific objectives and/or through preparing for future human exploration activities.

Robotic Precursor System Robotic spacecraft that are developed to execute missions that prepare for and support future human exploration, and to accomplish science objectives.

Safety-Critical Software Software is safety-critical if it meets at least one of the following criteria:
1. Resides in a safety-critical system (as determined by a hazard analysis AND at least one of the following:
    a. Causes or contributes to a hazard.
    b. Provides control or mitigation for hazards.
    c. Controls safety-critical functions.
    d. Processes safety-critical commands or data.
    e. Detects and reports, or takes corrective action, if system reaches hazardous state.
    f. Mitigates damage if a hazard occurs.
    g. Resides on the same system (processor) as safety-critical software.
2. Processes data or analyzes trends that lead directly to safety decisions (e.g., determining when to turn power off to a wind tunnel to prevent system destruction.)
3. Provides full or partial verification or validation of safety-critical systems, including hardware or

software subsystems.

Segment Used in the CTS requirements development process to express the identity of two or more elements mated together and operating jointly in a given set of mission phases. Segments defined this way facilitate functional decomposition of capabilities throughout the reference Exploration Spiral 3 mission. For example, the In-Space Transportation Segment is comprised of the CEV and an Earth Departure Stage, and comprises the CTS from the Earth Orbit Operations Mission Phase until CEV-EDS separation during the Destination Vicinity Operations Mission Phase. Other segments were defined as the CEV Launch Segment (CEV and CLV operating through separation in Earth orbit), the Destination Transportation Segment (CEV and LSAM operating in the lunar vicinity), and the Earth Return Segment (CEV only, upon separation from LSAM Ascent Stage).

Spiral Development Process A phased system of system development process that allows increasing capabilities to be achieved in support of long range objectives. While work can be accomplished concurrently against the objectives associated with multiple spirals, the completion of all objectives for a given spiral is considered necessary to enable achievement of the succeeding spiral. See associated definitions for Exploration Spirals.

Strategy to Task to Technology Process (STTP) Use of engineering analysis to validate architectural and mission design approaches, and identify technology investment needs.

Surface Operations Phase Starts at the completion of landing on the destination surface, including propulsion system shutdown and safing. Representative mission activities include: science operations, system and operational testing, surface EVA, assembly and maintenance, vehicle checkout, and preparation for ascent. Phase ends at initiation of ascent from the destination surface (i.e., T0).

System of Systems A set or arrangement of interdependent systems that are related or connected to provide a given capability. The loss of any portion of the System of Systems will degrade the performance or capabilities of the whole. The systems contained in the Exploration System of Systems (ESS) are: the Crew Transportation System, Cargo Delivery System, In-Space Support System, Destination Surface System, Robotic Precursor System, and Ground Support System. Requirements, constraints, and guidelines that apply to all human and robotic exploration systems are levied against the Exploration System of Systems, and may apply against any or all Exploration Spirals, as specified. The term “System of Systems” is sometimes expressed synonymously as “Super-system”.

Threshold Used in requirements language to define the minimum capability necessary to satisfy the requirement.

Transfer Volume The passageway between two connected element that can contain crew.

Wedge Angle The angle change that must be accomplished (i.e., delta-V capability) to exit an Earth Reference Orbit and achieve a desired Lunar Reference Orbit (see Lunar Reference Orbit).

5.2 Acronyms and Abbreviations

CDS	Cargo Delivery System
CE&R	Concept Exploration and Refinement
CEV	Crew Exploration Vehicle
CEVLS	Crew Exploration Vehicle Launch Segment
CLV	Crew Launch Vehicle
CG	Center of Gravity
CTS	Crew Transportation System
DSS	Destination Surface System
EDS	Earth Departure Stage
EI	Entry Interface
ECLSS	Environmental Control/Life Support System
ESMD	Exploration Systems Mission Directorate
ESS	Exploration System of Systems
EVA	Extra-Vehicular Activity
GN&C	Guidance, Navigation, and Control
GSS	Ground Support System
IRD	Interface Requirements Document
ILS	Integrated Logistics Support
IS^3	In-Space Support System
ITA	Independent Technical Authority
JIMO	Jupiter Icy Moon Orbiter
LEO	Low Earth Orbit
LRL	Lunar Robotic Lander
LRO	Lunar Robotic Orbiter
LSAM	Lunar Surface Access Module
NEDD	Natural Environments Definition for Design
NODIS	NASA Online Directives Information System
NP	NASA Publication
NPD	NASA Policy Documents
NPR	NASA Procedural Requirement (Document)
OAG	Operations Advisory Group
OSMA	Office of Safety and Mission Assurance
OSP	Orbital Space Plane
PRA	Probabilistic Risk Assessment
RFP	Request for Proposals
RPS	Robotic Precursor System
SRR	System Requirements Review
STD	Standard (Document)
STTP	Strategy to Task to Technology Process (or Panel)
TBD	To Be Determined
TBR	To Be Resolved
TPS	Thermal Protection System

5.3 Requirements Taxonomy

The following table is provided as a key to understanding the taxonomy used for requirement Unique ID numbers (i.e., the Unique ID number is shown at the beginning of each requirement statement).

System/Segment	Req. Number	Spiral
ESS (Exploration System of Systems Technical) **EPR** (Exploration Programmatic Requirements) **EPG** (Exploration Programmatic Guidelines)	**0001 - 9999**	**A = Spiral 1** **B = Spiral 2** **C = Spiral 3** **D = Spiral 4** **E = Spiral 5** **F = Spirals 1&2** **G = Spirals 2&3** **H = Spirals 1,2,3**
CTS (Crew Transportation System) **CVS** (CEV Launch Segment) **CEV** (Crew Exploration Vehicle) **CVL** (CEV Launch Vehicle)		